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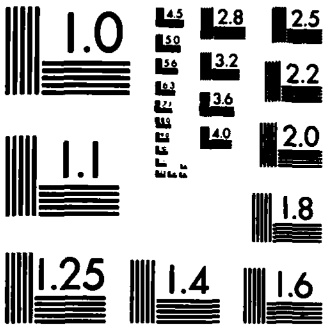

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AerodyneDallas

FINAL REPORT

CONTRACT NO. DAAK70-82-C-0070

FUEL CONSUMPTION REDUCTION FOR DIESEL POWER GENERATOR SETS THROUGH THE APPLICATION OF AN ADVANCED TURBOCHARGER OPERATING AT CONSTANT SPEED

PREPARED BY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Turbocharged diesel engine driven gen sets in the past, having not been able to respond to instantaneous zeor-to-full load changes and maintain frequency within mil. std. 705B specifications. This is because of the poor turbocharger transient response commonly called "turbo lag". A VATN (variable area turbine nozzle) turbocharger, partially developed under Army contracts DAAK70-78-C-0031 and DAAK70-80-C-0146, eliminates turbo lag.

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Calculations were made to estimate the engine operating conditions for a four cylinder turbocharged diesel engine driven, precision, 30KW-400Hz gen set. Similar calculations were made for the current, naturally aspirally, six cylinder diesel driving the same gen set. These calculations showed that the VATN feature would allow the turbo to hold a constant intake manifold pressure at all load levels thereby eliminating turbo lag. Furthermore a fuel saving of 9% or more was estimated based on the mil. std. 705B 100 hour duty cycle.

A controller was designed and built to position the turbine nozzle so as to maintain the intake manifold pressure determined from the calculations. The four cylinder engine, with the VATN turbocharger and controller, was dynamometer tested. Test data confirmed the estimated fuel savings and operation of the turbocharger-engine system.

The six cylinder diesel was removed from a GFE 30KW-400Hz, precision, gen set and replaced by the four cylinder, turbocharged engine. Transient test methods 608.1a, 619.1c, and 619.2b of mil. std. 705B were conducted on the demonstrator gen set. All compliance criteria were satisfied. It can be concluded that a DED gen set equipped with a VATN turbocharger can meet the military gen set transient requirements.

SUMMARY

The efforts of two previous Army contracts (DAAK70-78-0031 and DAAK70-80-0146) contributed significantly toward the development of a small turbocharger which features variable area turbine nozzles (VATN), a ball bearing supported rotor, and a self-contained lubrication system. The objective of the current contract (DAAK70-82-0070) is to demonstrate that a 30KW-400Hz precision gen set, equipped with a VATN turbocharger, can comply with DoD gen set transient specifications. Heretofore poor turbocharger transient response (turbo lag) caused the turbocharged, DED gen set to lose frequency beyond acceptable DoD limits during an instantaneous change in load from 0 to full load.

Engine operating conditions were calculated using a computer math model, partially developed under the two previous Army contracts. This model was adjusted to match calculated and measured fuel consumption values for current DED gen set. Estimates from these calculations show a potential fuel savings of 9% or more with a four cylinder, turbocharged engine replacing the current six cylinder, naturally aspirated, engine.

Data from the engine model calculations was used to design a controller for the VATN. The controller is simply a spring acting on a piston which is balancing the spring force against the pressure difference across the piston between intake manifold and ambient pressures. The controller was fabricated mainly from aluminum. Functionally, the controller moves the VATN control rod so as to hold nearly a constant manifold pressure. Therefore the engine operates essentially like a naturally aspirated engine i.e. no lag with sudden changes.

The turbocharger, with controller, was installed on a four cylinder diesel engine and tested at the engine manufacturer's (White Engine Co.) facility. Fuel consumption data was used to further refine the engine math model. Calculations confirmed at least a 9% fuel savings for the 30KW-400Hz gen set. The engine was then sent to Libby Welding Co. for mating with a generator and further tests.

A GFE 30KW-400Hz DED gen set, powered by the bill-of-materials six cylinder engine, was supplied to Libby by MERADCOM. Libby did all the work necessary to remove the six cylinder naturally aspired engine and replace it with the turbocharged four cylinder engine received from White Engine Co. to form the demonstrator unit. Transient gen set tests were performed by Libby. The tests were method 608.1a, method 619.1c, and method 619.2b of mil. std. 705B. The demonstrator unit exceeded all compliance requirements associated with the above three gen set tests.

From the effort of this contract, it can be concluded that a DED precision gen set equipped with a VATN turbocharger can comply with DoD transient requirements.

PREFACE

This report was prepared by Aerodyne Dallas under U.S. Army Contract DAAK70-82-0070, issued by the Electro-Mechanical Division of the U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, and was under the technical direction of Mr. John R. Arvin.

This report covers the results of the work performed from March 1980 to September 1982, at which time the program was completed.

Special thanks go to the personel at White Engine Co. and Libby Welding Co. for their assistance and guidance in conducting this work.

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I. INTRODUCTION

Turbocharging of internal combustion engines can result in improved fuel economy by down-sizing and/or reducing the engine speed. The application of the turbocharger then brings the power output back to the orginal naturally aspirated value. Additional fuel consumption benefits can be realized for the turbocharged diesel engine due to improved air fuel ratio.

A turbocharger has been developed by Aerodyne Dallas which employs several advanced design features. These features include variable area turbine nozzles (VATN), an overhung rotor supported by two ball bearings located near the cool enviroment at the compressor inlet, and a self-contained lubrication system. Placing the bearings in the cool portion of the turbocharger and eliminating the need for engine lube oil, addresses the factors which most significantly contribute to turbocharger failure. The turbine variable geometry and extremely low parasitic losses associated with the ball bearing system are features which contribute to improved turbocharger performance, especially transient response. Also, the VATN feature is a more efficient method of controlling boost pressure (via turbine power output) than a wastegate.

Figure 1 is a crossectional view of the Aerodyne turbocharger with associated nomenclature. Two previous Army contracts, DAAK70-78-C-0031 and DAAK70-80-C-0146, greatly contributed to the development of this turbocharger. Based on the successful engine testing and the broad operating range of the VATN turbine, a proposal was made to Fort Belvoir to apply this turbocharger to an Army diesel engine driven (DED) generator set. The degree of turbocharging is severly limited for military DED gen sets because of turbocharger lag. The poor transient response of conventional turbochargers will not allow the engine to respond to a 0 to full load transient within DoD gen set performance specifications. The VATN feature of the Aerodyne turbocharger eliminates the turbocharger lag problem. Nearly a constant boost pressure is maintained at all gen set load levels through proper control of the turbine nozzles. A program was contracted with MERADCOM, Fort Belvoir, to demonstrate that the VATN turbocharger would enable a turbocharged, 30KW-400Hz, DED gen set to satisfy the transient requirements for military gen sets. The program was to culminate with a demonstrator 30KW-400Hz gen set powered by a four cylinder diesel replacing a 6 cylinder, naturally aspirated diesel. The program elements included the following five main tasks:

* Analysis using engine math model

* Design and fabricate controller

* Refurbish turbocharers and check performance of controller and turbocharger

* Engine dynamometer test

FIGURE 1 - Turbocharger Crossection and Nomenclature

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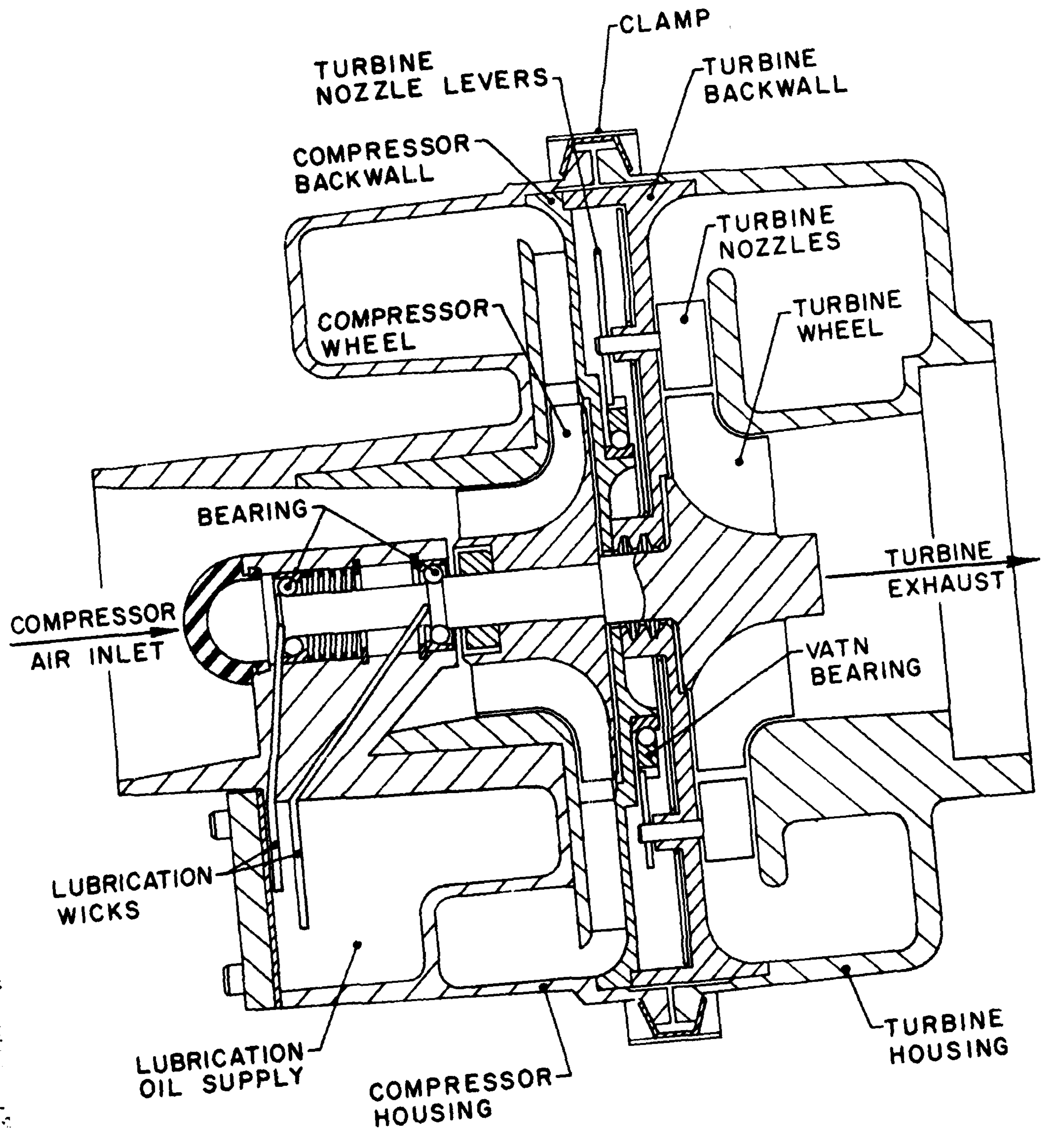


* Generator electrical tests as described in Military standard 705B:

  Method 608.1a

  Method 619.1c

  Method 619.2b

Sucessful compliance with DoD gen set transient response requirements wi'' enable the military to realize the benefits of the turbocharged diesel. These benefits include a smaller, lighter, more fuel efficiency engine. There is the potential for using a family of engines over a wide range (gen set sizes. This would have a favorable impact on inventory size, ar number of items in inventory, logistics, and possibly acquisition cost.

The purpose of this report is to present the work performed under Army contract DAAK-70-82-0070 as applied to the above tasks. The report organization follows these tasks.

II ESTIMATE ENGINE PERFORMANCE

The purpose of this task was to estimate engine performance at various full load air/fuel ratios (A/F) and to select a range of boost pressures which give the desired A/F values. Also, as part of this task, the effect of altitude was assessed and the effect of allowing the turbo speed to decrease at low engine loads was investigated.

CURRENT FUEL CONSUMPTION

MERADCOM, at Fort Belvoir, provided electrical generator efficiencies as a function of load and fuel consumption data for several current DED generator sets of interest. Table 1, below, lists this data and also gives the total fuel used during one mil. std. 705B duty cycle (also defined in table 1).

TABLE 1 - Army supplied data

	% of full load					Total for 705B duty cycle
	0	25	50	75	100	
generator efficiency	0	65%	74%	79%	82%	
Mil Std 705B duty cycle time, hr	4	24	24	24	24	100 hr
gal/hr (15KW, 60 Hz)	0.59	0.89	1.18	1.48	1.77	130.0 gal
gal/hr (30KW, 60 Hz)	1.01	1.52	2.03	2.53	3.04	222.9 gal
gal/hr (30KW, 400 Hz)	1.37	1.88	2.39	2.89	3.40	258.9 gal
gal/hr (60KW, 60 Hz)	2.04	3.05	4.08	5.10	6.13	448.8 gal

CALCULATED FUEL CONSUMPTION

The analytical work for this task was done using a computerized math model partially developed under the two previously mentioned Army contracts. The electrical generator efficiencies shown in Table I were used to calculate the engine output power required for all gen sets considered. Table II gives the horsepower output required for the 15 and 30 KW gen sets.

TABLE II - Required engine output horsepower

	% of full load				
	0	25	50	75	100
15KW	0	7.73	13.59	19.10	24.53
30KW	0	15.46	27.18	38.20	49.06

A multiplying factor was applied to the math model indicated thermal efficiency correlation such that the calculated total fuel usage for one 705B cycle of the 15KW-60Hz, and the 30KW-60Hz gen sets was near the values shown in table I. The final multiplying factor was 0.9306. Table III shows a comparison of the measured and calculated values of fuel consumption in terms of gallons of fuel for one mil. std. duty cycle.

TABLE III- Comparison of measured and calculated fuel consumption for one 705B duty cycle

GEN SET	MEASURED gal	CALCULATED gal	CALC / MEAS	ERROR
15KW-60Hz	130.0	127.5	0.9808	- 1.92%
30KW-60Hz	222.9	230.0	1.0319	+ 3.19%
30KW-400Hz	258.9	246.1	0.9506	- 4.49%

Table V at the end of this section of the report list several of the parameters of interest taken from each of the calculated points. Calculation numbers 1 through 5 are for the current 15KW-60Hz gen set, numbers 6 through 10 are for the current 30KW-60Hz gen set, and numbers 11 through 15 are estimates of the 30KW-400Hz gen set. The fuel rates are based on a fuel density of 7.311 pounds mass per gallon.

DEMONSTRATOR GEN SET CALCULATIONS

Calculation points 16, 23, and 28 (see table V) show that the full load minimum fuel consumption, for the three air/fuel ratios (A/F) considered, occured at A/F = 32.0. The three A/F values were 28, 32, and 36; the corresponding fuel flows were 3.064, 2.991, and 2.997 gallons/hour respectively. A/F of 28 and 32 were chosen to define the range of interest for this program. The compressor pressure ratios (P2/P1) were 1.298, 1.490, and 1.748 for the three full load A/F values. Calculation points 16 through 20 are for the various load levels for the gen set with a turbocharger controller holding the turbocharger at a constant compressor discharge pressure, P2, as the load was reduced from 100 to 0%. As will be seen in a later section of this report, the simplicity of the turbocharger controller hardware allowed the boost pressure to drop slightly with gen set load. Calculation points 23 through 27 are similar to 16-20 except the turbocharger boost is set to give an A/F of 32 at full load.

The effect of holding the turbine vanes in a fixed position for loads below 50% were investigated for the condition where the full load A/F was 28. The five calculation points for this control mode are 16, 17, 18, 21, and 22 in table V. From points 21 and 22 it can be seen that the turbocharger pressure ratio (P2/P1) dropped as the load decreased with the vanes fixed. It was felt that a small benefit might be derived from improving the engine ΔP (intake manifold pressure, P2, minus exhaust manifold pressure, P3). A negative engine ΔP is reflected as additional work required by the piston to pump the engine gas flow against the pressure gradient across the engine. Table IV, below, lists the fuel consumption comparisons.

TABLE IV - Comparison of fuel usage for 30KW-400Hz gen set operating over 705B duty cycle

TABLE V POINT NO.	GEN SET AND OPERATION DESCRIPTION	GALLONS	CALC / MEAS
	Measured current gen set with 298CID	258.9	
(11-15)	Calculated current gen set with 298CID	246.1	.9506
(16-20)	Calculated for 28 A/F, const P2, 226CID	221.5	.8555
(16-18, 21,22)	Calculated for 28 A/F, const vanes 50-0% 226CID	221.3	.8548
(23-27)	Calculated for 32 A/F, const P2, 226CID	221.2	.8544

From table IV it can be seen by comparing the calculated current fuel usage to that for the constant P2, 28 A/F, case that an estimated 10.0% improvement in fuel consumption may be realized over the mil. std. 705B duty cycle. Also the fuel consumption for the const P2 and 28 A/F and 32 A/F are the same within 0.15%. Furthermore, holding the turbine vanes fixed from 50% load down to 0 load would only reduce the calculated fuel usage less than 0.10%. Figure 2 graphically presents the measured and calculated fuel consumption for the various current gen sets considered in this study as a function of load. Figure 3 shows the fuel consumption estimated for the demonstrator gen set operating with the turbocharger controller set to give a full load A/F of 28. The data in figure 2 is also shown subdued in figure 3. The shaded area between the circle-symbols line and the actural data for the 30KW-400Hz gen set depicts the estimated fuel savings which can be achieved by substituting a turbocharged, 4 cylinder, 226 CID diesel for a naturally aspirated, 6 cylinder, 298 CID diesel engine.

Figure 4 illustrates the compressor operating point as the full load A/F ratio is varied from 28 to 32 to 36 for the 30KW-400Hz gen set. The compressor trim, or size, depicted by the map in figure 4 is the same as the turbocharger compressor used in the previous contract (DAAK70-80-0146).

EFFECT OF ALTITUDE

The effect of altitude was determined by calculating operating points at 5000 and 8000 feet, points 29 and 30 in table V. These points are also spotted on the compressor map, figure 4. In calculating the two altitude points, it was assumed that full load was maintained, and that the turbocharger controller would maintain a constant difference between intake manifold and ambient pressure (P2 - Pamb). This gave a reduction in A/F from 28 at sea level to 23.4 at 5000 feet and to 20.4 at 8000 feet. It was therefore concluded that constant load could be maintained up to altitude of 8000 feet, since the A/F did not drop below 18.

This concluded the analytical study effort.

FIGURE 2 - FUEL CONSUMPTION FOR EXISTING GENERATOR SETS AT VARIOUS LOADS - MEASURED AND CALCULATED

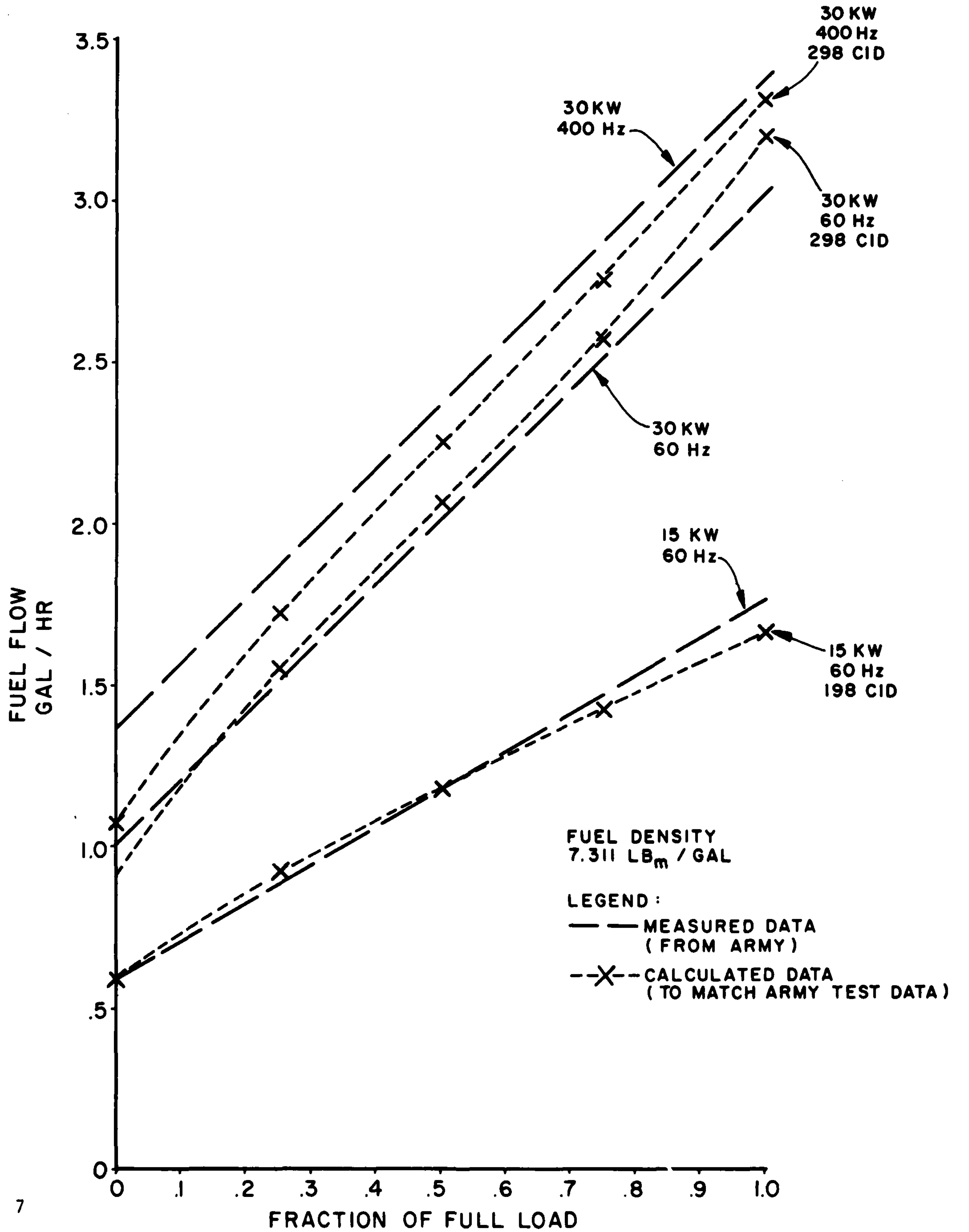


FIGURE 3- FUEL CONSUMPTION ESTIMATED FOR DEMO GENERATOR SET AT VARIOUS LOADS

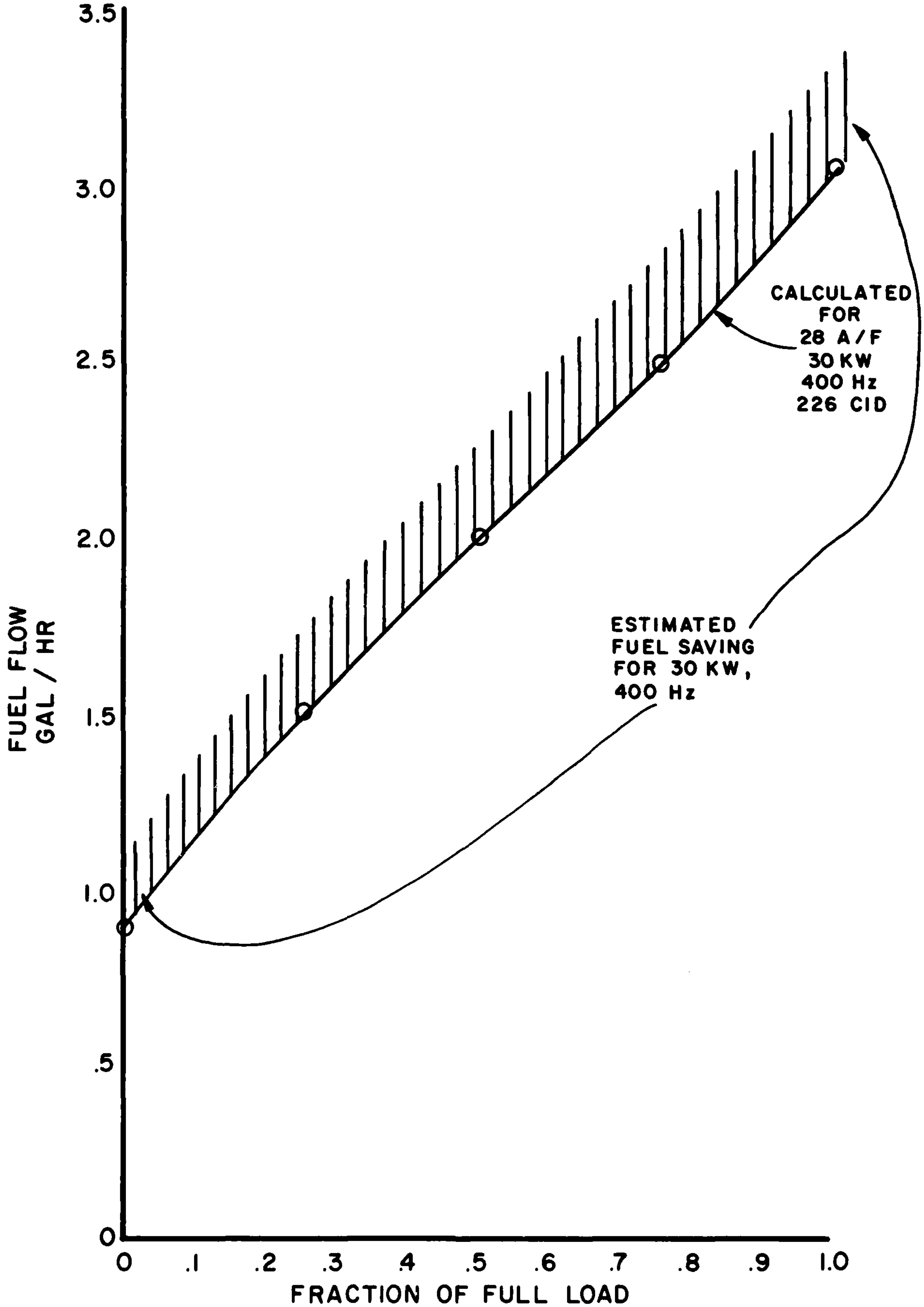


FIGURE 4 - COMPRESSOR MAP

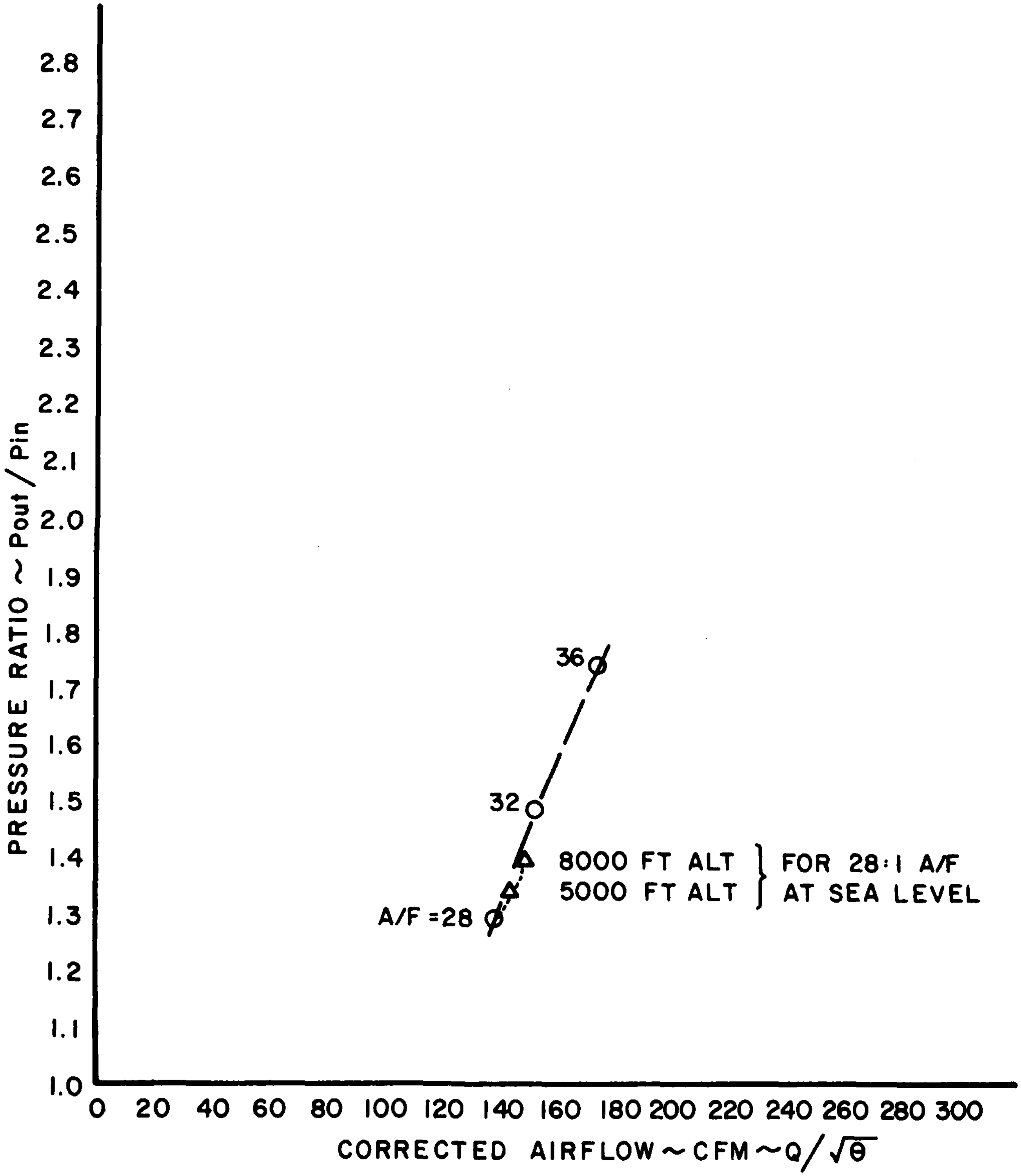


TABLE V - Summary of Calculated Engine Operating Points

CALC NO.	DISP In^3	NE RPM	ALT Ft.	P2/P1	A/F	FUEL FLOW Gal/Hr.	POWER BHP	LOAD FRACTION %	η ITH MULT
1	198	1800	0	N/A	34.0	1.675	24.5	100.	.9306
2					39.9	1.430	19.1	75.	
3					48.2	1.183	13.6	50.	
4					61.7	0.924	7.7	25.	
5					95.7	0.596	0.	0.	
6	298	1800	0	N/A	26.7	3.213	49.1	100.	
7					33.2	2.586	38.2	75.	
8					41.3	2.075	27.2	50.	
9					55.1	1.558	15.5	25.	
10					95.7	0.897	0.	0.	
11	298	2000	0	N/A	28.3	3.322	49.1	100.	
12					34.1	2.760	38.2	75.	
13					41.7	2.258	27.2	50.	
14					54.3	1.733	15.5	25.	
15					87.9	1.072	0.	0.	
16	226	2000	0	1.298	28.0	3.064	49.1	100.	
17					34.3	2.506	38.2	75.	
18					42.7	2.013	27.2	50.	
19					57.3	1.502	15.5	25.	
20					98.1	0.877	0.	0.	
21	226	2000	0	1.222	54.7	1.499	15.5	25.	
22				1.153	93.1	0.844	0.	0.	
23	226	2000	0	1.490	32.0	2.991	49.1	100.	
24					38.2	2.502	38.2	75.	
25					47.2	2.028	27.2	50.	
26					62.1	1.537	15.5	25.	
27					101.4	0.937	0.	0.	
28	226	2000	0	1.748	36.0	2.997	49.1	100.	
29	226	2000	5000	1.358	23.4	3.228	49.1	100.	
30			8000	1.401	20.4	3.422	49.1	100.	

III TURBOCHARGER CONTROLLER

The next task was to design a control device which would maintain boost pressure at the levels calculated and reported in the previous section.

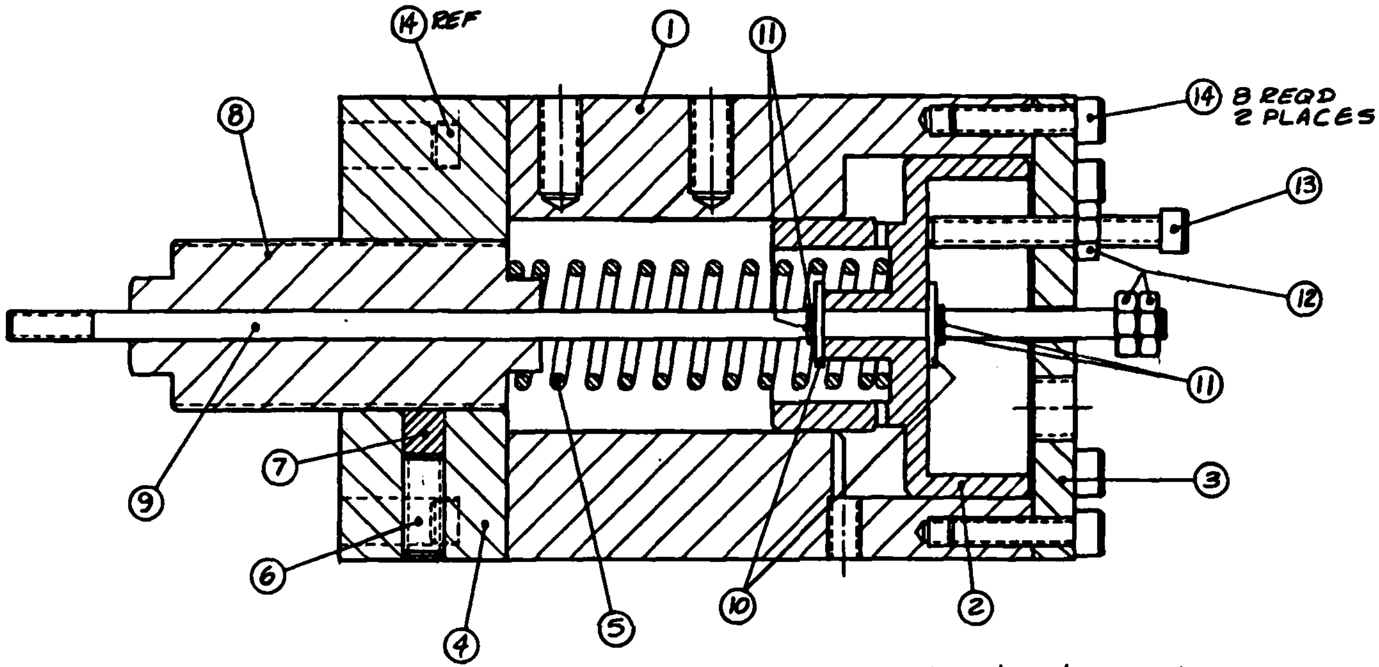
DESIGN

The design of the controller was kept as simple as possible. Past experience at Aerodyne in developing a simple controller for automotive application was drawn upon. The controller design is a piston and spring arrangement which maintains a nearly constant difference in pressure between the intake manifold and ambient. The final design is shown in Figure 5, Aerodyne drawing 2638. Intake manifold pressure, P2, is vented to the chamber formed by piston (2) and cover plate (3) in drawing 2638. Between the opposite side of the piston and the adjustable screw (8) another chamber if formed; this chamber is vented to ambient. Piston rod (9) is connected to the turbocharger vane control rod. When the P2 - Pamb pressure difference acting over the piston area developes a force greater than that applied by spring (5) to the piston, then piston rod moves to the left in figure 5. The nuts (12) on the end of the piston rod (9) limit the travel to the left and the position of bolt (13) limits the travel to the right. Screw (8) was designed long enough to provide a range of spring preload values by simply compressing the spring. The length available for the spring was defined such that a long spring with a low spring constant could be used. This tended to minimize the effect of piston position on control pressure. The following equation gives the relationship of the various parameters:

$$P2 - Pamb = Ap \cdot K\,(Lf - Lpl + \text{vane travel}) \qquad \text{(eqn 1)}$$

Where
* P2 is the desired intake manifold pressure, control pressure
* Pamb is ambient pressure
* Ap is piston area
* K is spring constant, force/change in length
* Lf is spring free length
* Lpl is length of spring after being preloaded by screw (8)
* Vane travel is the length of travel of the vane control rod from the full closed position

From the above equation it can be seen that P2, the control pressure, can be changed by turning screw (8) thereby changing Lf - Lpl. Also, during operation, the control pressure will be higher with the vanes open (large vane travel value) than closed (small vane travel). The vanes move toward the open position as the load increases. Screws (12) on the end of rod (9) and screw (13) serve as mechanical stops which can be adjusted to limit the maximum and minimum travel of rod (9). This sets the vane open and closed positions. Screw (13) would be used



ITEM	QTY	DESCRIPTION
14	16	BOLT (8-32 x .75 LONG)
13	1	BOLT (10-32 x 1.38 LONG)
12	3	NUT (10-32)
11	4	KEEPER (TRU-ARC 5103-18)
10	2	WASHER (A/D 2637)
9	1	PISTON ROD (A/D 2636)
8	1	ADJUSTMENT SCREW (A/D 2635)
7	1	PLUG (A/D 2634)
6	1	SET SCREW (1/4-20 x .625 LONG)
5	1	SPRING (LC067J10 MW)
4	1	COVER PLATE (A/D 2633)
3	1	COVER PLATE (A/D 2623-2)
2	1	PISTON (A/D 2621-2)
1	1	HOUSING (A/D 2622)

AERODYNE DALLAS

title VATN CONTROLLER GENERATOR SET USE

drawn	date	chkd	date	approved	date
ETS	6/21/82				

matl	scale	dwg no
	2/1	2638

FIGURE 5 - LAYOUT OF GENERATOR SET TURBOCHARGER CONTROLLER

to increase the minumum vane position for calculation points 21 and 22 in Tabe V.

FABRICATION

The body, cover plotes, and piston were machined from aluminum. The adjustable screw (8) was machined from mild steel. The remaining parts were purchased "off-the-shelf".

A spring was selected to give the range of boost pressures needed for 28 to 32 full load A/F. These pressures were 4.3 and 7.2 psig respectively. The spring was selected from the Lee Spring Company 1982 catalog. The Lee stock number is LC-067J-10. The physical characteristics are as follows:

* free length = 3.0 inches (Lf in equation 1)
* spring rate = 10 lbf/in (K in equation 1)
* solid height - .883 inches (fully compressed spring)

IV TURBOCHARGER AND CONTROLLER TESTING

Bench tests on the controller were made in order to determine the change in control pressure as a function piston rod movement (spring deflection) and preload. Preload was documented as the length of the adjustable screw (8) exposed outside the cover plate (4). Figure 6 presents the bench test data for two adjustable screw (8) preload positions. These two positions approximately match the 4.3 and 7.2 psig control pressures previously mentioned. When the amount of screw (8) thread exposed was changed from 1.195 inches to 0.495 inch, the term Lf-Lpl in equation 1 was increased by 0.700 inch thereby increasing the control pressure as shown in figure 6. At a given position of screw (8), say 0.495 inches of thread exposed, the data in figure 6 shows how the control pressure increases as the rod moves from 0 to 0.300 inches. This movement is synonymous with "vane travel" in equation 1.

Little refurbishment was needed to bring the turbochargers to working order. New turbine housings were made in order to eliminate holes left from instrumentation during the previous contract. One of the two turbochargers required a new turbine backwall. This was also due to instrumentation from the previous contract. Brief tests were made to confirm the compressor operation. One of the output data sheets is shown in figure 7. Mass flow rate to the turbine was not measured. The data points in figure 7 are near the "backbone" of the map. By comparing the compressor volumetric flow, pressure ratio, corrected speed, and efficiency to the compressor map in figure 4, it can be seen that the Army turbocharger compressor performance was the same as the map.

FIGURE 6 - CONTROL PRESSURE AS A FUNCTION OF DEFLECTION AND PRELOAD

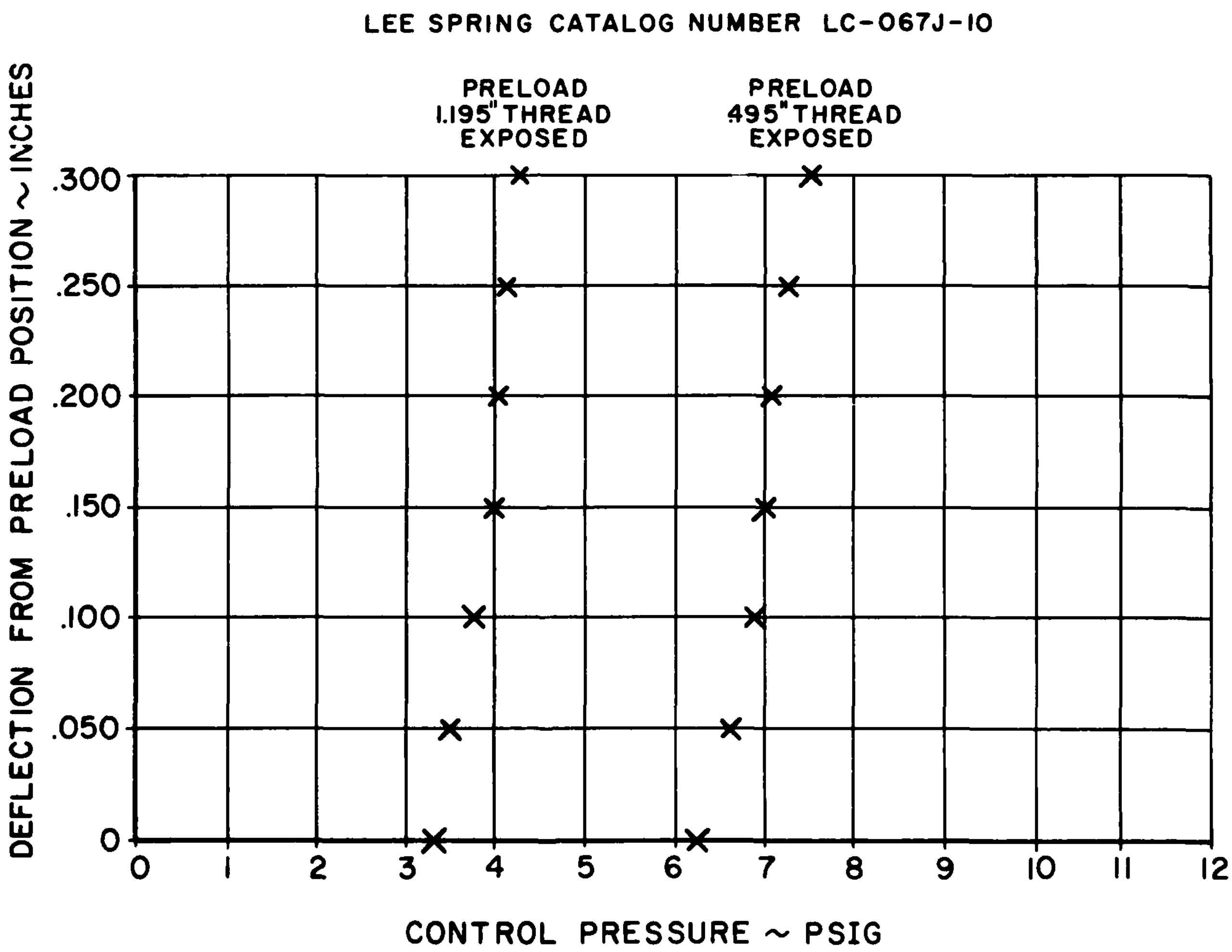


FIGURE 7 - Compressor Checkout Test Data

TIME and DATE are 04:05:14:43:36

S/N 69A ARMY .250/119(

barometer is 29.46

Rdg#	5	6	7	8	9
Time (Hr:Mn)	14:55	15:02	15:13	15:20	15:27
Barometer (psi)	14.466	14.466	14.465	14.465	14.465
C O M P R E S S O R					
Vol Flow (scfm)	107.9	141.3	161.1	186.3	199.6
Corr Mass Flow, W√O/D (#/sec)	0.1375	0.1801	0.2053	0.2374	0.2544
Pressure Ratio, Rc	1.3495	1.4927	1.6604	1.8714	2.1633
Corr Speed, N/√O (rpm)	59774	70547	80149	90501	100196
Eff (%)	72.17	72.75	72.03	71.02	69.72
Eff, w/o .0008HT (%)	77.20	76.36	74.89	73.31	71.65
FC, V/Um-in	0.5421	0.6008	0.6011	0.6142	0.5922
LC, DH'/Ut^2	0.5238	0.5091	0.5042	0.4953	0.5042
Corr Mass Flow, W√O/D (%des)	46.2	60.5	69.0	79.8	85.5
Corr Speed, N/√O (%des)	59.8	70.5	80.1	90.5	100.2
Act Speed, N (rpm)	60820	71840	81850	92630	102960
Tin (deg R)	537.0	537.9	540.9	543.4	547.7
Tout (deg R)	603.6	627.6	658.1	693.6	741.7
Pin (psia)	14.198	14.122	14.070	14.006	13.971
Ps diff 3/Pin	1.0196	1.0250	1.0288	1.0336	1.0363
Ps diff 4+/Pin	1.0191	1.0246	1.0283	1.0331	1.0358
Pout (psia)	19.160	21.080	23.362	26.212	30.224
T U R B I N E					
Expansion Ratio, Re	1.3184	1.4572	1.6048	1.8088	2.0325
Corr Speed, N/√O (rpm)	49795	56315	61555	66511	70278
Corr Speed, N/√O (%des)	82.1	92.8	101.4	109.6	115.8
Vane Throat Dim. (in)	0.3000	0.3000	0.3000	0.3000	0.3000
Mass Flow, (#/sec)	0.0000	0.0000	0.0000	0.0000	0.0000
Corr Mass Flow, W√O/D (Eng#/sec)	0.0000	0.0000	0.0000	0.0000	0.0000
Eff (%, meas DT)	41.22	72.63	69.93	68.05	64.79
Eff (%, compr+brg+windg)	$$$$$$$$$$	$$$$$$$$	$$$$$$$$	$$$$$$$$	$$$$$$$$
U/V'	0.8228	0.8023	0.7870	0.7653	0.7442
Load Coef	0.3045	0.5642	0.5644	0.5810	0.5849
Tin (degR)	773.8	844.1	917.1	1006.1	1113.3
Tout (degR)	749.8	782.5	837.7	902.4	985.9
Pin (psia)	18.950	20.818	22.753	25.432	28.315
Ps rotor in/Pin	0.7635	0.6951	0.6359	0.5690	0.5111
Pout (psia)	14.374	14.286	14.178	14.060	13.931
P O W E R B A L A N C E					
Compr Power (hp)	3.112	5.493	8.184	12.139	16.819
Turb Power (hp)	0.000	0.000	0.000	0.000	0.000
Brg Oil DT (degF)	0.1	0.2	0.2	0.3	0.2
Brg Oil DT Power	0.000	0.000	0.000	0.000	0.000
Brg Frctn Eqn Power	0.000	0.000	0.000	0.000	0.000
Compr windage (hp)	0.0160	0.0247	0.0355	0.0505	0.0717
Turb windage (hp)	0.0017	0.0025	0.0035	0.0047	0.0063
Power bal error (%)	$$$$$$$$$$	$$$$$$$$	$$$$$$$$	$$$$$$$$	$$$$$$$$

V ENGINE DYNAMOMETER TESTING

Engine dynamometer testing was conducted by White Engines Inc, the manufacturer of the engine. The test engine is model D2300-T. This engine employs more recent technology than the D198ER: the four cylinder diesel engine normally used for DoD gen set applications. The salient features of the D2300-T are as follows:

* displacement - 226. in ^{3}
* bore and stroke - 4 x 4.5 inches
* four cylinder, open chamber, diesel
* 16:1 compression ratio

The engine was tested in a "stripped" configuration. White Engines recommended a value of 6.5 horsepower to account for the difference between the stripped configuration and the installed configuration as applied to a gen set operating at 2000 rpm. The engine was fitted with a precision fuel pump capable of controlling the engine to the DoD specifications. Figure 8 is the engine dynamometer test data. Numbers were assigned to each operating point, item 1 figure 8. The BSFC (brake specific fuel consumption), item 12 in figure 8, was plotted verses BHP (brake horsepower), item 5 in figure 8, and presented as figure 9.

ANALYSIS

Engine operating points were calculated using the same computerized math modelas discussed in section II of this report. The results of these calculations are tabulated in table VI at the end of this section of the report. Calculation numbers 31 through 34 correspond to engine dynamometer test point numbers 7 through 10. Likewise, calculation number 35 through 38 correspond to point number 23 through 26 in figure 8. As can be seen from table VI the multiplying factor on indicated thermal efficiency was 0.9306 for calculations 31-38: the same value as was used for the analytical work reported in section II. The BSFC, power, and load fraction values listed in table VI were all adjusted to reflect the 6.5 BHP adjustment to account for the difference between the installed and stripped engine. Each calculation was actually run at 6.5 BHP less than the value in table VI. Then the BSFC was adjusted. The BSFC values are shown in figure 9 as triangle and diamond symbols. A new multiplying factor on indicated thermal efficiency was determined which allowed the calculated data (points 39-42) for test points 23-26 to match the test data very closely. The new multiplier was 0.9678; 4% greater that the 0.9306 value deduced from D198ER and D298ER diesel engine driven gen set fuel consumption measurements. Calculation points 39 through 42 are also plotted in figure 9. The solid line as compared to the dashed line in figure 9 shows the effect of the change in the multiplying factor. Also, it can be seen that the dashed line closely fits the data for test points 23-26. The shaded in diamonds are the symbols for the dashed line.

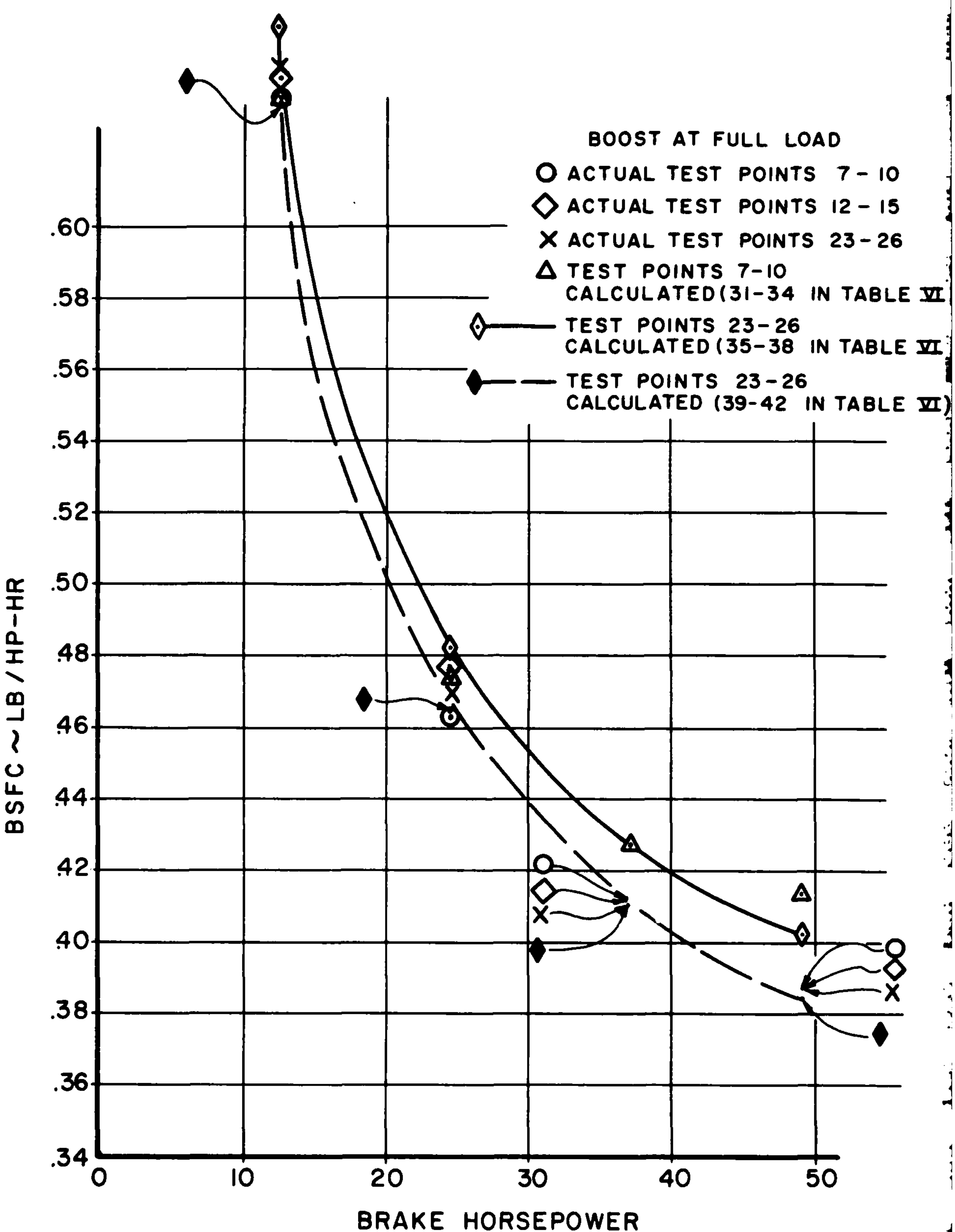
FIGURE 8 – ENGINE DYNAMOMETER TEST DATA

WHITE ENGINES, INC	ENGINE TEST SHEET	MODEL D-232?T (x293)	SERIAL NO. Y63450439?	NO. OF CYL. 4	BORE 4"	STROKE 4½"	CU. IN. 226	COMP. RATIO 16:1	STAND NO. 8	PROJ. NO. 15	TEST NO. 2005	SHEET NO. 4
ENGINE HOURS AT START 21	FUEL CONTR. EQUIP. Roosa	MODEL NO. DB2-433	SERIAL NO. 40-3056552	FUEL DF #2	SPEC. GRAV. —	LUBE BRAND Mobil	GRADE #30	HRS. 21	OPERATOR Miller		DATE 6-28-82	
HOURS AT END OF SHEET 23	EQUIP. Open Water System / Laminar AirFlow Element			NOZZLE & GAUGE 40-3055251	PRESS. 2000 PSI	STATIC TIMING 24° BTC			OBJECT OF TEST Aerodyne Turbocharger [illegible]			

Point #	1		2	3	4	5	6		7	8	9	10	11	1st Ba	12	13	14	15	16		17	18		19		20	21	22	3rd Ba	23	24	25	26	27
2 ENGINE RPM	2000		2000	2000	2000	2000	2000		2000	2000	2000	2000	2000		2000	2000	2000	2000	2000		2000	2000		2000		2000	2000	2000		2000	2000	2000	2000	2000
3							N/L						N/L						N/L			N/L		N/L				N/L		100%	75%	50%	25%	N/L
4 BEAM LOAD	6.50		73.5	55.1	36.8	18.4	4.5		73.5	55.1	36.8	18.4	4.5		73.5	55.1	36.8	18.4	4.5		18.4	4.5		4.5	4½ turns of nut	36.8	18.4	4.5		73.5	55.1	36.8	18.4	4.5
5 BHP OBS.	4.333		49.00	36.73	24.53	12.27	3.00		49.00	36.73	24.53	12.27	3.00		49.00	36.73	24.53	12.27	3.00		12.27	3.00		3.00		24.53	12.27	3.00		49.00	36.73	24.53	12.27	3.00
6 BHP CORR.																																		
7 TORQUE																														128.67	96.45	64.43	32.22	7.58
8 BMEP																														85.86	64.36	42.98	21.50	5.36
9 CORR. FACT.																																		
10 FUEL - TIME FOR .5 LB	104.2	2000 RPM	95.2	119.0	159.0	228.0	327.2	REPEAT RUN	95.0	119.0	168.5	230.0	327.0		95.0	119.0	154.0	228.8	324.0		222.0	328.0	ADJUSTED TURBO @ 25%	322.0	ADJUST TURBO @ 75%	157.2	224.0	321.8	2000 RPM PART LOADS	95.0	119.2	156.5	227.2	302.0
11 LBS/HR	17.27		18.91	15.13	11.32	7.89	5.50		18.95	15.13	11.36	7.83	5.50		18.95	15.13	11.69	7.87	5.56		8.11	5.49		5.59		11.45	8.04	5.59		18.95	15.10	11.50	7.92	5.96
12 BSFC	.399		.386	.412	.461	.643	1.833		.387	.412	.463	.638	1.833		.387	.412	.477	.641	1.863		.661	1.830		1.863		.467	.655	1.863		.387	.411	.469	.645	1.787
13 FUEL mm3/STROKE																																		
14 FUEL TEMP.	84		91	92	92	92	92		91	93	93	93	93		94	93	93	94	94		96	96		95		96	96	96		93	95	95	96	96
15 FUEL PRESS.																																		
16 TIMING																																		
17																																		
18 AIR INLET TEMP.	89		94	93	92	92	91		96	97	98	95	96		101	98	96	96	98		100	98		98		100	100	97		100	102	104	100	97
19 INT. MAN. TEMP.	152		153	146	138	129	126		155	149	132	133	134		178	175	171	157	161		167	154		153		166	147	135		193	185	176	171	173
20 EXH. MAN. TEMP.	804		906	753	620	484	388		907	764	628	485	393		878	732	612	501	425		504	416		414		626	498	400		854	740	624	513	445
21																																		
22 EXH. TEMP. OUT	605	@ PDF	801	664	542	430	346		780	679	556	430	345		757	615	502	430	355		423	365		351		527	444	341		706	626	519	423	353
23																																		
24 INT. MAN. PRESS.	8.1		7.1	6.4	5.3	5.1	4.6		7.1	5.8	5.5	5.1	5.3		10.5	10.7	10.7	9.4	8.5		9.3	8.5		7.3		8.5	5.9	4.3		13.1	12.1	10.9	11.4	10.6
25 EXH. MAN. PRESS.	6.7		5.7	5.9	5.7	6.7	7.1		5.7	5.4	5.9	6.7	8.1		8.3	10.1	12.2	13.4	13.9		12.9	14.2		11.7		9.5	7.8	6.7		10.5	11.5	12.5	17.1	18.4
26																																		
27 OIL TEMP.	167		195	197	194	192	192		190	194	192	190	188		198	195	183	190	188		192	191		190		194	193	192		191	197	196	193	192
28 OIL PRESS.	58	Barometer 28.96 "Hg Std	56	57	57	57	57		57	56	57	57	57		56	56	57	57	57		57	57		57		56	56	56		56	56	56	56	56
29																																		
30 WATER IN TEMP.	81		159	170	164	163	164		147	156	158	157	153		163	172	158	151	148		161	160		155		160	161	159		162	169	167	164	162
31 WATER OUT TEMP.	181		183	186	183	183	183		184	183	183	182	180		184	187	184	180	180		183	183		182		184	183	181		186	186	184	183	183
32 Air/Fuel Ratio			32.68	40.45	53.00	76.05	109.09		32.93	40.45	53.87	77.39	111.27		35.78	45.21	59.54	85.39	119.78		82.86	121.31		115.92		58.17	72.61	108.41		37.68	46.49	60.52	88.14	116.78
33 EXH. SMOKE	.9		1.1	.7	.4	.2	.3																											
34 BLOW-BY	1.1		1.1	1.1	1.0	1.0	1.0																											
35 TURBO SPEED	60,000		57,480	55,420	52,000	51,000	49,480		57,630	53,600	52,340	51,080	51,860		66,400	66,850	66,700	63,800	61,500		63,480	61,400		58,000		61,850	54,200	46,720		71,600	70,000	67,700	68,500	66,750
36 AIR FLOW	10.6		10.3	10.2	10.0	10.0	10.0		10.4	10.2	10.2	10.1	10.2		11.3	11.4	11.6	11.2	11.1		1.2	11.1		10.8		11.1	10.4	10.1		11.9	11.7	11.6	11.7	11.6
37 Eng. hrs.														20															22					
38 Oil hrs.														20															22					

('½ turn more : Changed preload 20 turns) →

FIGURE 9- MEASURED BRAKE SPECIFIC FUEL CONSUMPTION FOR A 226 CID ENGINE (TAKEN AT WHITE ENGINE COMPANY) AT 2000 RPM



REVISED FUEL CONSUMPTION ESTIMATE

Having refined the math model to match the engine dynamometer data (subject to the 6.5 BHP correction), the model was once again executed to estimate the fuel consumption of the demonstrator, 30KW-400Hz gen set. The new multiplying factor on indicated thermal efficiency was used and, at each load point, the intake manifold pressure measured on the engine dynamometer was also employed rather than a constant value. (See figure 8, item 24). These calculation results are included in table VI as calculation points 43 through 47. The revised fuel consumption for one mil. std. 705B 100 hour duty cycle is 212.0 gallons as compared to 221.5 from section II of the report. The calculated value for the current 6 cylinder D298ER engine is 246.1 gallons: the measured value for the current engine is 258.9 gallons. Figure 10 is a copy of figure 2 but with the revised demonstrator estimates included i.e. calculation points 43-47 from table VI.

One other calculation was run to estimate the operating conditions at full rated load, 8000 foot altitude, on a hot day (std day temperature + 60 F); see point 48 in table VI. The A/F ratio dropped from 32.3 to 22.8 and the fuel consumption increased from 2.879 to 3.115 gallons/hours. The A/F of 22.8 should be adequate to run full load.

As an appendix to this report, copies of the computer output for calculation points 43-48 have been included for those readers who may wish more detail than is contained in table VI.

FIGURE 10 - FUEL CONSUMPTION AT VARIOUS LOADS WITH REVISED ESTIMATE FOR DEMO GENERATOR SET

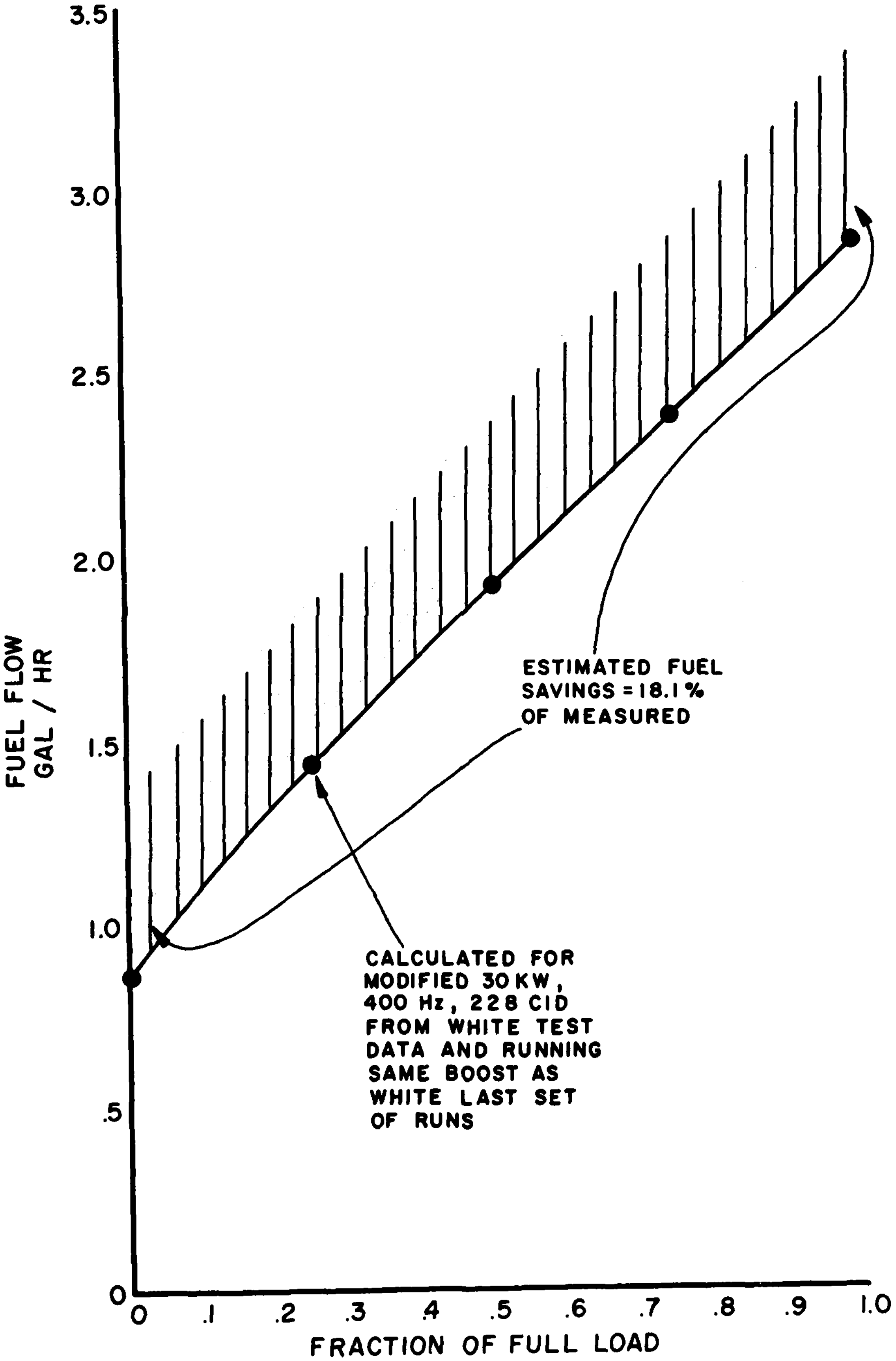


TABLE VI - Summary of Calculations Relating to Engine Dynamometer Test and Refined Fuel Consumption Estimates

CALC NO.	DISP In^3	NE RPM	ATL Ft.	P2/P1	A/F	FUEL FLOW Gal/Hr.	ADF POWER BHP	ADJ LOAD FRACTION %	η ITH MULT	ADJ BSFC LB/ HP-Hr	TEST POINT NO.
31	226	2000	0	1.246	27.7	2.764	49.0	100.	.9306	.4124	7
32				1.200	34.5	2.158	37.0	73	.9306	.4265	8
33				1.190	46.3	1.599	24.5	45.	.9306	.4764	9
34				1.176	68.9	1.068	12.3	20.	.9306	.6365	10
35	226	2000	0	1.452	32.2	2.693	49.0	100	.9306	.4018	23
36				1.418	39.4	2.158	37.0	73	.9306	.4265	24
37				1.376	51.5	1.614	24.5	45	.9306	.4816	25
38				1.366	74.6	1.102	12.3	20	.9306	.6569	26
39	226	2000	0	1.452	33.2	2.587	49.0	100	.9678	.3859	23
40				1.418	40.6	2.079	37.0	73	.9678	.4108	24
41				1.376	53.0	1.557	24.5	45	.9678	.4645	25
42				1.366	77.1	1.067	12.3	20	.9678	.6357	26
								non-adj		non-adj	
43	226	2000	0	1.438	32.3	2.879	49.1	100	.9678	.4296	
44				1.404	38.0	2.410	38.2	75	.9678	.4612	
45				1.364	46.1	1.942	27.2	50	.9678	.5220	
46				1.354	61.0	1.458	15.5	25	.9678	.6896	
47				1.354	102.7	0.866	0	0	.9678	-	
48	226	2000	8000	+ 1.590	22.8	3.115	49.1	100	.9678	.4637	

VI GENERATOR TRANSIENT RESPONSE TESTS

Having completed the dynometer testing, the engine was shipped to the Libby Welding Co. Inc, with the Aerodyne turbocharger and controller installed.

DEMONSTRATOR GEN SET CONFIGURATION

A GFE 30KW-400Hz precision gen set was shipped to Libby from Fort Belvoir. Libby removed the D298ER, six cylinder diesel engine, made the necessary modifications, and installed the four cylinder engine in place of the six cylinder engine. This included lengthening the shroud which ducts air into the radiator to compensate for the difference in engine length of approximately 10 inches. Also, as a small "add-on" to the contract, rubber mounts were used to attach the electrical generator and engine to the gen set frame. This was done so that noise measurements can be taken at Fort Belvoir, at a later date, to determine the effect of the soft mounts.

TRANSIENT ELECTRIAL TESTS

Three transient tests were called-out in the contract. These are defined by mil. std. 705B, Generator Sets, Engine Driven, Methods of Test and Inspection:

(1) Method 608.1a, Frequency and Voltage Regulation, Suitability and Transient Response Test (Short-Term).

(2) Method 619.1c, Voltage Dip for Low Power Factor Load Test.

(3) Method 619.2b, Voltage Dip and Rise for Rated Load Test.

All electrical tests were performed by Libby at their test facility in Kansas City, Mo. These test are routinely conducted by Libby as part of their day-to-day activity building a variety of DoD gen sets. Figure 11 is a copy of the data taken by Libby which show that the demonstrator, turbocharged, DED gen set exceeded the criteria for compliance for the three designated tests. (See last two pages of figure 11). Figure 12 is a copy of a portion of the oscillograph record made by Libby as part of the method 608.1a test. The second page of figure 12 shows that the recovery time was 0.3 seconds and frequency change was 4.2 Hz when the load was instantaneously changed from 0 to 100%. When the load was changed from 100% to no-load, the frequency change was 2.6 Hz and the recovery time was 0.25 seconds.

Additional transient tests were conducted with the load instantenously changing from zero to 40KW, 30% greater than the rated generator load. The performance specifications were again met.

After successful completion of the testing at Libby, both the demonstrator gen set and the D298ER engine removed from the GFE gen set were shipped to Fort Belvoir.

FIGURE 11 - Generator test data

OFFICIAL TEST RECORD

MFR LIBBY WELDING COMPANY, INC.
MODEL MEP 114A
SERIAL NO RZ 40334
RATING 30 KW, 400 Hz.
T.P
CONTRACT OR ORDER
NO. DAAJ08-81-C-1764

LIBBY WELDING CO.
2201 MANCHESTER
KANSAS CITY, MO. 64126

DESCRIPTION STABILIZATION

TEST NUMBER 8
METHOD NO. 608.1
DATE 17 Aug 82
TESTED BY FK Miller

GOVT INSP

INST. NO														
READ NO.	TIME	Voltage L1-N	Voltage L2-N	Voltage L3-N	Line Current L1	Line Current L2	Line Current L3	Power	Frequency	Extr Field Volts	Extr Field Curr.	Coolant Block	intake HG	AMBIENT TEMP
UNITS		Volts	Volts	Volts	Amps	Amps	Amps	KW	Hz	Volts	Amps			
FACTOR		x1	x1	x1	x1	x1	x1	x1	x1	x1	x1			
1	1335	119.4	119.9	120.0	105.0	104.8	105.0	30.3	400.2	60.6	5.0	177	+12.8	92
2	1345	119.2	119.8	119.8	104.0	103.9	104.3	30.1	400.3	60.5	5.0	177	+12.7	94
3	1355	119.1	119.7	119.7	103.8	103.7	104.3	29.8	400.4	60.5	5.0	177	+12.6	94
		Failed 1st 608.1 (Test 8) High Speed Stop Set at 410 Vice 450)												
1	0940	119.9	120.4	120.1	104.1	104.1	104.1	30.2	400.0	60.6	5.1	174	12.6	82
2	0950	119.8	120.3	120.0	104.3	104.3	104.2	30.1	400.0	60.6	5.1	173	12.6	88
3	1000	119.8	120.2	120.0	104.3	104.3	104.2	30.1	400.0	60.6	5.1	174	12.6	87

REMARKS

EXG-8 SHEET 37 OF 54

FIGURE 11 - (con't)

OFFICIAL TEST RECORD

MFR LIBBY WELDING COMPANY, INC.
MODEL MEP 014A
SERIAL NO RZ 40334
RATING 30 KW, 400 HZ.
T. P

CONTRACT OR ORDER NO. DAAJ09-81-C-1764

LIBBY WELDING CO.
2201 MANCHESTER
KANSAS CITY, MO. 64126

DESCRIPTION REGULATOR AND GOVERNOR STABILITY AND TRANSIENT RESPONSE, 60/400 HZ, 125°F AMBIENT

TEST NUMBER
METHOD NO. T608.1
DATE 18 Aug 82
TESTED BY JKM

GOVT INSP

INST. NO

READ NO.	Voltage L1-N	Voltage L2-N	Voltage L3-N	Line Current L1	Line Current L2	Line Current L3	Pwr. Out	Freq.	Extr. Field Volt.	Extr. Field Curr.	Bandwidth Volt	Bandwidth Freq.	Regulation Volts	Regulation Freq.	Freq O/S	Surge O/U	Freq Rec	Load Change From	Load Change To	INTAKE DEPRESS IHG
UNITS	Volts	Volts	Volts	Amps	Amps	Amps	KW	Hz	Volts	Amps	%	%	%	%	%	%	Sec	From	To	
FACTOR	x1	x1	x1	x1	x1	x1	x1	x1	x1	x1							x1			
	Rated Load (Start)																			
1	119.8	120.2	120.0	109.3	109.3	109.2	30.0	400.0	60.6	5.1	0	0.05	-	-	-	-	-	R/L		12.7
2	121.0	121.1	120.2	0	0	0	0	410.0	61.3	3.8	0	0	0.08	0	0.65	-	0.25	R/L	N/L	11.8
3	119.8	120.2	120.0	-	-	-	30.4	400.0	-	-	0	0.05	0.08	0	-	1.05	0.3	N/L	R/L	
4	120.0	120.2	120.2	-	-	-	0	400.0	-	-	0	0	0.08	0	0.6	-	0.25	R/L	N/L	
5	119.8	120.2	120.0	-	-	-	30.8	400.0	-	-	0	0.15	0.08	0	-	1.0	0.3	N/L	R/L	
6	120.1	120.2	120.2	-	-	-	0	400.0	-	-	0	0	0.08	0	0.6	-	0.25	R/L	N/L	
7	119.8	120.2	120.0	-	-	-	30.7	400.0	-	-	-	-	0.08	0	-	1.05	0.25	N/L	R/L	
		3/4 Rated Load																		
8	119.7	120.2	120.1	78.3	78.4	78.1	22.3	400.0	60.8	4.9	0	0.05	-	-	-	-	-	3/4		12.5
9	120.1	120.2	120.2	0	0	0	0	400.1	61.3	3.8	0	0.05	-	-	-	-	-	3/4	N/L	11.9
10	119.8	120.2	120.1	-	-	-	22.4	400.1	-	-	0	0.05	-	-	-	-	-	N/L	3/4	
11	120.1	120.2	120.2	-	-	-	0	400.1	-	-	0	0.05	-	-	-	-	-	3/4	N/L	
12	119.8	120.2	120.1	-	-	-	22.4	400.1	-	-	0	0.05	-	-	-	-	-	N/L	3/4	
13	120.1	120.2	120.2	-	-	-	0	400.1	-	-	0	0.05	-	-	-	-	-	3/4	N/L	
14	119.8	120.2	120.1	-	-	-	22.4	400.1	-	-	-	-	-	-	-	-	-	N/L	3/4	

REMARKS

SHEET 46 OF 54

FIGURE 11 - (con't)

MFR LIBBY WELDING COMPANY, INC.
MODEL MEP 114A
SERIAL NO RZ 40334
RATING 20 KW, 400 HZ.
T. 10

CONTRACT OR ORDER
NO. DAAJ09-81-C-1764

OFFICIAL TEST RECORD

LIBBY WELDING CO.
2201 MANCHESTER
KANSAS CITY, MO. 64126

DESCRIPTION REGULATOR AND GOVERNOR STABILITY AND TRANSIENT RESPONSE - 60/400 HZ.

TEST NUMBER
METHOD NO. T608 1
DATE 18 Aug 82
TESTED BY [signature]

GOVT INSP

INST. NO

READ NO.	Voltage L1-N	Voltage L2-N	Voltage L3-N	Line Current L1	Line Current L2	Line Current L3	Pwr. Out	Freq.	Extr. Field Volt.	Extr. Field Curr.	Bandwidth Volt	Bandwidth Freq.	Regulation Volts	Regulation Freq.	Freq. Surge O/S	Freq. Surge U/S	Freq. Rec	Load Change From	Load Change To	INT PRE I H;
UNITS	Volts	Volts	Volts	Amps	Amps	Amps	KW	Hz	Volts	Amps	%	%	%	%	%	%	Sec			
FACTOR	x1	x1	x1	x1	x1	x1	x1	x1	x1	x1							x1			
		2/4	Rated	Load																
15	119.9	120.2	120.1	52.2	52.1	52.3	15.2	400.1	61.1	4.4	0	0.05	-	-	-	-	-	2/4	RL	11.9
16	120.1	120.2	120.2	0	0	0	0	400.1	61.4	3.8	0	0.05	-	-	-	-	-	2/4	N/L	11.9
17	120.0	120.2	120.1	-	-	-	15.5	400.2	-	-	0	0.05	-	-	-	-	-	N/L	2/4	
18	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0.05	-	-	-	-	-	2/4	N/L	
19	120.0	120.2	120.1	-	-	-	15.6	400.2	-	-	0	0.05	-	-	-	-	-	N/L	2/4	
20	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0.05	-	-	-	-	-	2/4	N/L	
21	120.0	120.2	120.1	-	-	-	15.7	400.2	-	-	-	-	-	-	-	-	-	N/L	2/4	
		1/4 Rated Load																		
22	120.0	120.3	120.2	26.1	26.0	26.0	7.5	400.2	61.2	4.0	0	0.05	-	-	-	-	-	1/4	RL	12.
23	120.1	120.2	120.2	0	0	0	0	400.2	61.4	3.8	0	0.05	-	-	-	-	-	1/4	N/L	12.
24	120.0	120.3	120.2	-	-	-	7.5	400.2	-	-	0	0.05	-	-	-	-	-	N/L	1/4	
25	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0.05	-	-	-	-	-	1/4	N/L	
26	120.0	120.3	120.2	-	-	-	7.6	400.2	-	-	0	0.05	-	-	-	-	-	N/L	1/4	
27	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0.05	-	-	-	-	-	1/4	N/L	
28	120.0	120.3	120.2	-	-	-	7.6	400.2	-	-	-	-	-	-	-	-	-	N/L	1/4	

REMARKS

SHEET 47 OF 54

FIGURE 11 - (con't)

MFR LIBBY WELDING COMPANY, INC.
MODEL HEP 114A
SERIAL NO RZ 48339
RATING 30 KW, 400 HZ.
T.12

CONTRACT OR ORDER
NO. DAAJ09-81-C-1764

OFFICIAL TEST RECORD

LIBBY WELDING CO.
2201 MANCHESTER
KANSAS CITY, MO. 64126

DESCRIPTION REGULATOR AND GOVERNOR STABILITY AND TRANSIENT RESPONSE, 60/400 HZ.

TEST NUMBER 8
METHOD NO. T608.1
DATE 18 Aug 82
TESTED BY JKM

GOVT INSP

INST. NO

READ	Voltage			Line Current			Powr.		Extr. Field		Bandwidth		Regulation		Freq	Surge	Freq	Load		
NO.	L1-N	L2-N	L3-N	L1	L2	L3	Out	Freq.	Volt.	Curr.	Volt	Freq	Volts	Freq	O/S	U/S	Rec	Change		INTAKE PRESS
UNITS	Volts	Volts	Volts	Amps	Amps	Amps	KW	Hz	Volts	Amps	%	%	%	%	%	%	Sec	From	To	I. Hg
FACTOR	x1	x1	x1	x1	x1	x1	x1	x1	x1	x1							x1			
		Rated Load (End)																		
29	119.9	120.2	120.0	1038	1038	1038	30.0	400.2	60.7	50	0	0.1	-	-	-	-	-		R/L	12.8
30	120.1	120.2	120.2	0	0	0	0	400.2	61.4	3.8	0	0	0.08	0	0.6	-	0.25	R/L	N/L	12.2
31	119.8	120.2	120.0	-	-	-	30.3	400.2	-	-	0	0.1	0.08	0	-	1.0	0.25	N/L	R/L	
32	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0	0.08	0	0.6	-	0.25	R/L	N/L	
33	119.8	120.2	120.0	-	-	-	30.3	400.2	-	-	0	0.1	0.08	0	-	1.05	0.25	N/L	R/L	
34	120.1	120.2	120.2	-	-	-	0	400.2	-	-	0	0	0.08	0	0.6	-	0.25	R/L	N/L	
35	119.8	120.2	120.0	-	-	-	30.4	400.2	-	-	-	-	0.08	0	-	1.0	0.25	N/L	R/L	

REMARKS

SHEET 48 OF 54

FIGURE 11 - (con't)

Model No. MEP-
Serial No. FZ
Rating KW HZ T
Contract No. DAAJ09-81-C-1764

PRODUCTION TEST RESULTS

Libby Welding Company, Inc.
2201 Manchester Trafficway
Kansas City, Missouri 64126

Date
Test Engr.
Inspected

Test No.	Method Number	Method Title, Description of the Procurement Document Requirements, and Test Conditions	Procurement Requirement	Test Results	Compliance with Procurement Document
18	516.5	Reverse Polarity			
		Reverse Polarity Damage	None		
46	602.1	Voltage Modulation			
		% Modulation	1.0% Max.		
		Data Sheet & Photographs attached.			
47	T619.1c	Voltage Dip for Low Power Factor			
		(400 Hz, TP Sets)			
		Allowable voltage dip	75%		
		Recovery time	0.7 Sec. Max.		
		Data Sheet and Oscillograms attached.			
45b	T601.4	Voltage Waveform (Harmonic Analysis)			
		Harmonic % of fundamental	2% Max.		
		Notches, spikes, discontinuities in			
		waveform	None		
		Data Sheet and photographs attached.			
56/13	T512.1	Circuit Interrupter-Short Circuit (125°F)			
		a. Indicator light	On		
		B. Circuit breaker	Open		
		Data Sheet and Oscillographs attached.			
56/14	T512.3c	Overvoltage and Undervoltage Trip (125°F)			
		I. Overvoltage, 156 for 200 msec	156 volts		
		a. trip time	1.25 sec.		
		b. indicator light	ON		
		c. engine	Shut down		
		II. Undervoltage (TP Only)			
		a. indicator light	ON		
		b. circuit breaker	Open		
		c. 47 volt trip, instant.	47V/instant.		
		d. 95 volt trip time delay	95V/6+ 2 sec.		

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FIGURE 11 - (con't)

Model No. MEP-
Serial No. RZ
Rating KW HZ T
Contract No. DAAJ09-81-C-1764

PRODUCTION TEST RESULTS

Libby Welding Company, Inc.
2201 Manchester Trafficway
Kansas City, Missouri 64126

Date
Test Engr.
Inspected

Test No.	Method Number	Method Title, Description of the Procurement Document Requirements, and Test Conditions	Procurement Requirement	Test Results	Compliance with Procurement Document
56/15	T513.1c	Instrument Check (125°F)			
		a. % accuracy of frequency meter	1.0%		
		b. error in voltmeter 240V	10 volts		
		c. % error in current meter	6%		
		d. % error in wattmeter	10%		
		Data sheet attached.			
56/69	T655.1	D.C. Control (125°F)			
		a. DC control current	5 amps max.		
		b. Max. DC control voltage	Record		
		c. Min. DC control voltage	Record		
		d. cranking of set and set damage			
		when reversed battery polarity	None		
		e. difference between generator volt-			
		age waveform from battery connect-			
		ed to disconnected	None		
		TP Only			
		f. voltage bandwidth	1% max.		
		g. frequency bandwidth	.5%		
		TU Only			
		f. voltage bandwidth	4% max.		
		g. frequency bandwidth	3% max.		
56	710.1c	Generator winding temperature rise (125°F)			
		Stator coil temperature rise	100°C max.		
		Exciter field temperature rise	100°C max.		
		Data sheet and graph attached.			
		Hot Fuel Test (125°F)			
		Vapor lock	None		
		Difficult starting	None		
		Uneven running	None		

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FIGURE 11 - (con't)

Model No. MEP-
Serial No. RZ
Rating KW HZ T
Contract No. DAAJ09-81-C-1764

PRODUCTION TEST RESULTS

Libby Welding Company, Inc.
2201 Manchester Trafficway
Kansas City, Missouri 64126

Date 18/Aug./82
Test Engr. F.M.
Inspected

Test No.	Method Number	Method Title, Description of the Procurement Document Requirements, and Test Conditions	Procurement Requirement	Test Results	Compliance with Procurement Document
56/8	T608.1a	Short Term Frequency and Voltage Regulation, Stability and Transient Response, Tactical Precise 60/400 (125°F)			
		Max. frequency bandwidth	.5%	0.15 %	OK
		Max. frequency recovery time	1.0 sec.	0.3 SEC	OK
		Max. frequency overshoot	1.5%	1.05 %	OK
		Max. frequency regulation	.25%	0	OK
		Max. voltage bandwidth	1.0%	0	OK
		Max. voltage regulation	1.0%	0.08 %	OK
		Data sheet and chart attached.			✓
56/13	T512.2c	Circuit Interrupter (Overload) (125°F)			
		a. trip time 130% overload min.	8 ± 2		
		b. indicator light	ON		
		c. circuit breaker	Open		
		d. 110%-no trip	no trip		
		e. trip time for Phase A, 130% overload	8 + 2		
		f. trip time for Phase B, 130% overload	8 + 2		
		g. trip time for Phase C, 130% overload	8 + 2		
56/26	T511.1c	Regulator Range (125°F)			
		Min. voltage adjust L-N, 60 & 400 Hz	114		
		Max. voltage adjust L-N, 60 Hz	138.5		
		Max. voltage adjust L-N, 400 Hz	132		
		Min. voltage-mechanical stop 60 & 400 Hz	Measure		
		Max. voltage-mechanical stop 60 & 400 Hz.	Measure		
56/28	T511.2b	Frequency Adjustment Range (TP Only) (125°F)			
		Max. frequency adjust, 60 Hz.	62 to 65		
		Max. frequency adjust, 400 Hz.	420 to 430		
		Min. frequency adjust, 60 Hz.	58		
		Min. frequency adjust, 400 HZ.	370 to 390		
		Min. frequency-mechanical stop	Measure		

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FIGURE 11 - (con't)

Model No. MEP

Serial No. RZ

Rating KW HZ T

Contract No. DAAJ09-81-C-1764

PRODUCTION TEST RESULTS

Libby Welding Company, Inc.
2201 Manchester Trafficway
Kansas City, Missouri 64126

Date

Test Engr.

Inspected

Test No.	Method Number	Method Title, Description of the Procurement Document Requirements, and Test Conditions	Procurement Requirement	Test Results	Compliance with Procurement Document
56/29	T511.2b	Frequency Adjustment Range (TP Only) (125°F) Cont.			
		Max. frequency-mechanical stop	Measure		
		Underfrequency device activated	Note		
56/67	T608.2	Long Term Frequency and Voltage Stability,			
		(125°F), TP.			
		Maximum frequency bandwidth	1%		
		Maximum voltage bandwidth	2%		
		Transient Portion:			
		Max. frequency recovery time	1 sec.		
		Max. frequency overshoot	1.5%		
		Max. frequency undershoot	1.5%		
		Max. frequency regulation 0.25%			
		Data sheet and chart attached			
56/47	T619.1c	Voltage Dip for Low Power Factor. (125°F) - 400 HZ, TP			
		Allowable voltage dip	75% min.	78.4	—
		Recovery time	0.7 sec max.	.22	—
		Data sheet and oscillograms attached.		yes	✓
56/48	T619.2b	Voltage Dip and Rise (125°F) 400 Hz.TP			
		Voltage dip	88%	91	—
		Recovery time	0.5 sec max.	.19	—
		Voltage rise	112% max.	105.6	—
		Recovery time	0.5 sec. max.	.14	—
		Data sheet and oscillograms attached.		yes	✓

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FIGURE 12 - Portion of oscillograph chart

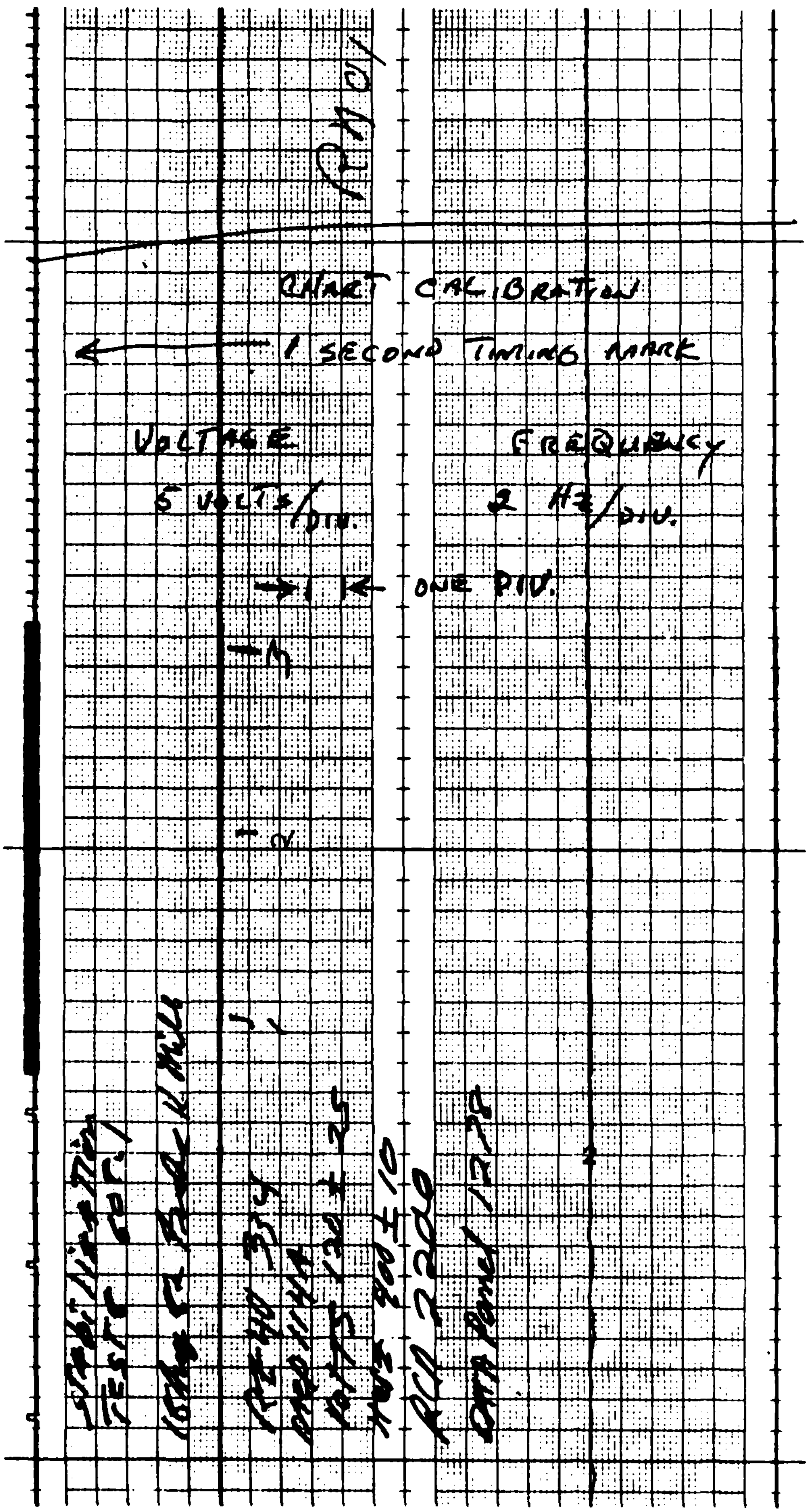
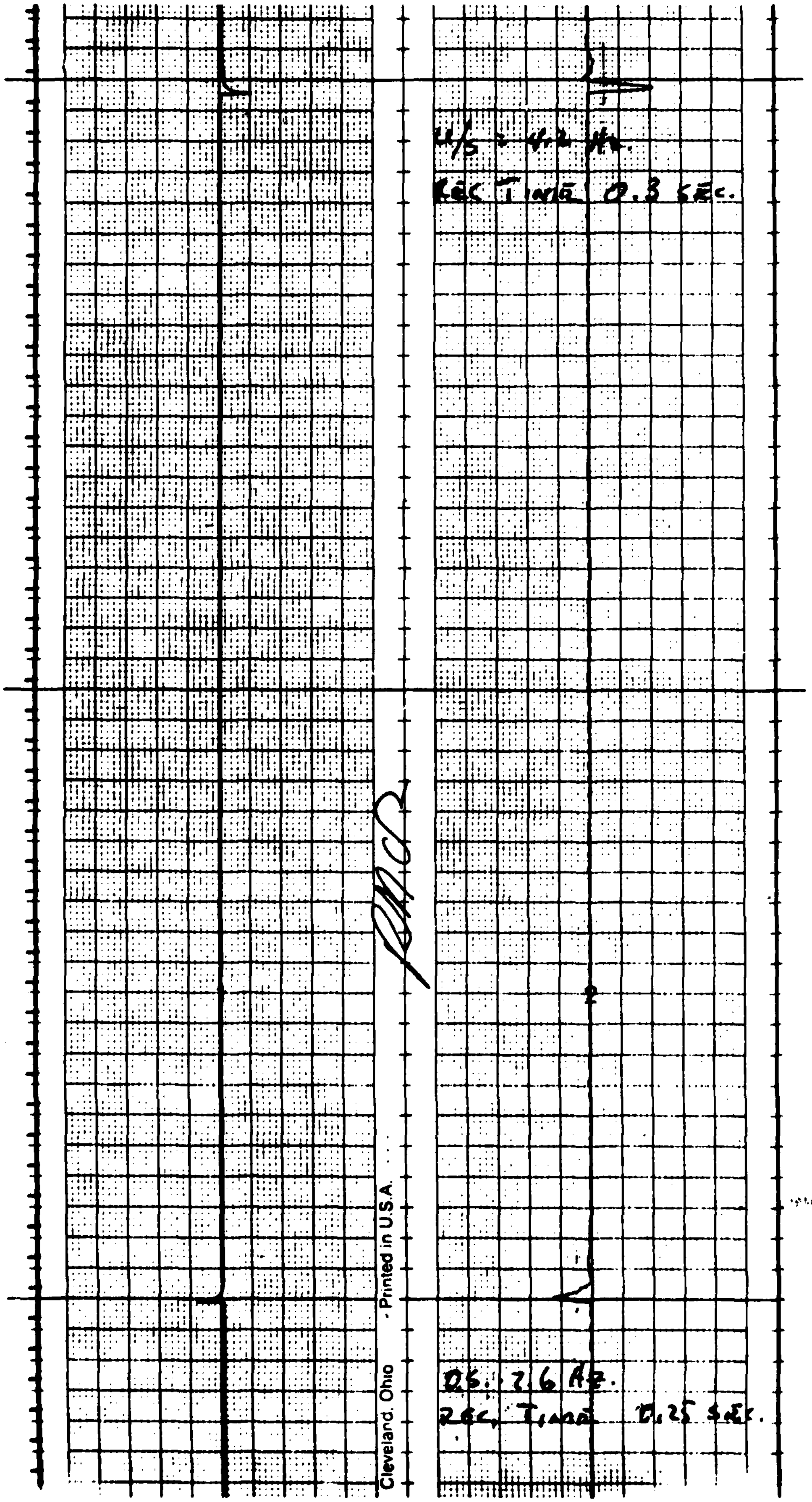


FIGURE 12 - (con't)



from no-load to 100% load

from 100% load to no-load

VII CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The major conclusion which can be drawn from the test results in section VI of this report is that a turbocharger with VATN (variable area turbine nozzle), and equipped with an appropriate VATN controller, eliminates the turbocharger lag problem which has, in the past, kept the turbocharged DED gen set from complying with mil. std. 705B. The second conclusion is based on analytical results in section II as improved from the engine testing discussed in section V. From these results it is estimated that the application of a down-sized, turbocharged diesel engine to the DED 30KW-400Hz gen set, currently powered by a naturally aspirated engine, can improve the fuel economy of the gen set by at least 9.0%. Also, the turbocharged gen set would be capable of delivering rated power up to an altitude of 8000 feet on a day with the temperature 60 F hotter than standard.

RECOMMENDATIONS

The engine math model was used to estimate the fuel savings which could be realized by applying a D 3400-T engine equipped with a VATN turbocharger to a 60KW-60Hz, DED gen set. The D 3400-T is the six cylinder version of the four cylinder D 2300-T. Table VII lists the results of the calculations. A constant intake manifold pressure of 12 psig was assumed. The inducated thermal efficiency multiplier deduced in section V was also used. Point numbers 49 through 53 are for sea level, standard day, operation over the load range. The calculated fuel consumption for one mil. std. 705B duty cycle is 370.2 gallons. This is 17.5% less than the 448.8 gallons required by the current gen set. It is also recommended that fuel consumption tests, hot day tests, and altitude test be performed on the demonstrator unit which resulted from this contract. This information will enable all the performance aspects of the turbocharged DED gen set, not investigated during this contract, to be assessed.

TABLE VII - Summary of Calculation Points Used to Estimate Fuel Savings for 60KW-60Hz DED Gen Set

CALC NO.	DISP In^3	NE RPM	ALT Ft.	P2/P1	A/F	FUEL FLOW Gal/Hr.	POWER BHP	LOAD FRACTION %	η_{ITH} MULT
49	339	1800	0	1.816	28.8	5.258	98.1	100	.9678
50				1.816	35.8	4.221	76.4	75	
51				1.816	45.4	3.320	54.4	50	
52				1.816	62.3	2.407	30.9	25	
53				1.816	112.0	1.323	0	0	
54	339	2000	0	1.816	30.9	5.403	98.1	100	
55	339	1800	8000	2.099	23.4	5.579	98.1	100	
56	339	1800	8000 + 60 F	2.099	19.6	6.028	98.1	100	

APPENDIX

Computer output for calculation number 43, TABLE VI

*****.967824XEFITH*****

4 CYL DIESEL ENGINE CALCULATION   ID=08/17/80 22:45:18 , 22.1167
WITH 1 TURBOCHARGER

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THRMO EFF
2000 RPM	128.66FT-LB	49.00 HP	85.85 PSIA	30.56 PSIA	1.60 PSIA	0.9245	0.4485
	174.47 N-M	36.54 KW	5.92 BAR	2.11 BAR	0.11 BAR	(0.920,0.924)	(1.0000)

DISPLCMNT	STROKE	COMPR RAT	AMB TEMP	AMB PRES	EQ RAT	TF	FMEP ADJ	QDOT
226.00 INC3	4.5000 IN	16.0000	59.000DEG F	14.700 PSIA	0.4645	-0.3550	1.0000	0.0000
3.70LITER	114.30 MM		15.130DEG C	1.0132 BAR	-21.0502	0.3553	18.5788	

COOL EFF	% BLOW BY	LEAK9-A	LEAK9-5	LEAK DT5	BSHC	BSCO	BSNO	BOSCH
0.0000	0.0000	0.0000	0.0000	0.0000	1.0571	1.8396	5.9901	0.3683

VAP PWR	VAP MEP	T MIX	T COMPRN	VAP DT	P COMPRN	VAP DP	WR/WGS
-0.00 HP	-0.00 PSI	626.85 DEG R	1818.43 DEG R	0.00 DEG R	980.97 PSI	-0.00 PSI	0.0307
-0.00 KW	-0.00 BAR	75.05 DEG C	737.04 DEG C	0.00 DEG C	67.62 BAR	-0.00 BAR	

F#	TYPE	W/WTOT	%VAP-MIX	VAP EF	BSFC-#/WH	BSFC-G/KW	LB/HR	CARB DP/P	AIR/FUEL
3	DIESEL	1.0000	0.0000	1.0000	0.4296	261.33	21.05	0.0000	32.326

2.879

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:::

RC	COMP EF	NCC	WCC	QC	AREA IN	DT IN	DT EX	EFSF	DT HT
1.4378	0.7200	69000 RPM	0.1890 LB/S	148.32 CFM	1.6696 SQIN	1.7030 IN	2.6660 IN	1.0000	10.5
	0.6349		0.0884 KG/S	0.0700 M3/S	1077.16 SQMM	43.256 MM	67.716 MM		

RETS	TURB EF	NCT	WCT	U/V'	VANE THRT	VANE HT	ROT TH A	EFSF	PW2/PW1
1.3098	0.8340	44823 RPM	0.2261 LB/S	0.7463	0.2157 IN	0.2500 IN	1.6500 SQIN	1.0000	1.0003
(1.3098)(	0.8340)(	0.0000)	0.1057 KG/S		5.4793 MM	6.3500 MM	1064.51 SQMM		

....

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	608.03	608.03	1272.49	1239.50	1229.86	1161.17
TEMP-DEG C	15.13	15.13	15.13	15.13	64.60	64.60	433.74	415.41	410.06	371.89
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	14.700	14.700	14.700	14.700	21.135	21.135	64.689	19.507	19.507	14.893
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.4568	1.4568	4.4588	1.3446	1.3446	1.0265
FLOW-LB/S	0.1890	0.1890	0.1890	0.1890	0.1890	0.1890	0.1949	0.1949	0.1949	0.1949
WRT/D-LB/S	0.1890	0.1890	0.1890	0.1890	0.1423	0.1423	0.0693	0.2269	0.2261	0.2877
FLOW-KG/H	308.6500	308.6500	308.6500	308.6500	308.6500	308.6500	318.1980	318.1980	318.1980	318.1980
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation number 44, TABLE VI

```
*****.967824XEFITH*****
 4  CYL DIESEL ENGINE CALCULATION            ID=00/17/00 23:11:48  , 17.2167
    WITH  1  TURBOCHARGER

ENG SPEED      TORQUE       NET POWER        BMEP          FMEP        ENG DELP(I-E)   VOL EFF      I.THRMO EFF
    2000 RPM   100.30FT-LB     38.19 HP      66.92 PSIA    29.89 PSIA      1.12 PSIA   0.9200          0.4466
               136.00 N-M      28.48 KW       4.61 BAR      2.06 BAR       0.08 BAR  (0.917,0.920)  (  1.0000)

DISPLCMNT      STROKE       COMPR RAT       AMB TEMP      AMB PRES        EQ RAT       TF   FMEP ADJ     QDOT
  226.00 INC3  4.5000 IN     16.0000          59.00DEG F   14.700 PSIA   0.3955   -0.3550    1.0000    0.0008
    3.70LITER  114.30 MM                      15.13DEG C    1.0132 BAR  -17.6157   0.3417   15.4120

 COOL EFF      % BLOW BY   LEAK9-A   LEAK9-5  LEAK DT5     BSHC      BSCO      BSNO      BOSCH
  0.0000        0.0000     0.0000    0.0000    0.0000     1.6063    2.7166    5.2770    0.4059

  VAP PWR        VAP MEP         T MIX         T COMPRN        VAP DT        P COMPRN        VAP DP          WR/WG5
    0.00 HP        0.00 PSI     619.19 DEG R   1799.34 DEG R    0.00 DEG R    959.85 PSI      0.00 PSI     0.0337
    0.00 KW        0.00 BAR      70.80 DEG C    726.43 DEG C    0.00 DEG C     66.16 BAR      0.00 BAR

F#   TYPE    M/MTOT  %VAP-MIX    VAP EF BSFC-#/HH BSFC-G/KH    LB/HR CARB DP/P  AIR/FUEL

3 DIESEL    1.0000    0.0000    1.0000    0.4612    280.55     17.62    0.0000    37.968
                                                                2.410
OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

       RC   COMP EF      NCC            WCC            QC          AREA IN         DT IN          DT EX        EFSF  DT HT
   1.4044   0.7200    67500 RPM     0.1858 LB/S   145.78 CFM    1.6696 SQIN    1.7030 IN      2.6660 IN    1.0000   9.3
            0.6390                  0.0868 KG/S   0.0688 M3/S  1077.16 SQMM    43.256 MM      67.716 MM

     RETS   TURB EF      NCT            WCT          U/V' VANE THRT         VANE HT        ROT TH A        EFSF PW2/PW1
   1.3131   0.8353    45550 RPM     0.2127 LB/S    0.7553   0.2031 IN       0.2500 IN       1.6500 SQIN 1.0000 0.9998
 ( 1.3131)( 0.8353)( 0.0000)        0.0994 KG/S             5.1585 MM       6.3500 MM    1064.51 SQMM

.............................................................................................................
```

	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	601.40	601.40	1175.54	1148.20	1139.70	1074.19
TEMP-DEG C	15.13	15.13	15.13	15.13	60.91	60.91	379.88	364.69	359.97	323.57
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	14.700	14.700	14.700	14.700	20.644	20.644	57.127	19.527	19.527	14.871
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.4229	1.4229	3.9376	1.3459	1.3459	1.0250
FLOW-LB/S	0.1858	0.1858	0.1858	0.1858	0.1858	0.1858	0.1907	0.1907	0.1907	0.1907
WRT/D-LB/S	0.1858	0.1858	0.1858	0.1858	0.1424	0.1424	0.0738	0.2135	0.2127	0.2712
FLOW-KG/M	303.3720	303.3720	303.3720	303.3720	303.3720	303.3720	311.3620	311.3620	311.3620	311.3620
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation number 45, TABLE VI

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*****.967824XEFITH*****
 4  CYL DIESEL ENGINE CALCULATION              ID=00/17/00 23:36:13  ,-1414.47
    WITH  1  TURBOCHARGER

ENG SPEED      TORQUE      NET POWER       BMEP          FMEP        ENG DELP(I-E)    VOL EFF        I.THRMO EFF
    2000 RPM   71.42FT-LB    27.20 HP     47.65 PSIA    29.21 PSIA     0.59 PSIA    0.9146            0.4416
               96.84 N-M    ·20.28 KW      3.28 BAR      2.01 BAR      0.04 BAR  (0.913,0.915)   (  1.0000)

DISPLCMNT      STROKE      COMPR RAT      AMB TEMP      AMB PRES         EQ RAT        TF  FMEP ADJ      QDOT
  226.00 INC3  4.5000 IN    16.0000      59.000DEG F   14.700 PSIA     0.3257   -0.3550    1.0000    0.0000
    3.70LITER  114.30 MM                 15.130DEG C    1.0132 BAR   -14.1977    0.3222   12.2616

 COOL EFF     % BLOW BY   LEAK9-A   LEAK9-5  LEAK DT5     BSHC      BSCO      BSNO      BOSCH
  0.0000        0.0000    0.0000    0.0000    0.0000    2.6053    4.2773    4.9266 .   0.4855

  VAP PWR       VAP MEP         T MIX        T COMPRN         VAP DT        P COMPRN          VAP DP          WR/WG5
    0.00 HP       0.00 PSI    610.20 DEG R  1776.75 DEG R    0.00 DEG R   934.27 PSI       -0.00 PSI       0.0373
    0.00 KW       0.00 BAR     65.80 DEG C   713.88 DEG C    0.00 DEG C    64.40 BAR       -0.00 BAR

F#   TYPE    W/WTOT  %VAP-MIX    VAP EF BSFC-#/HH BSFC-G/KH    LB/HR CARB DP/P  AIR/FUEL

 3 DIESEL   1.0000   0.0000    1.0000   0.5220    317.54     14.20   0.0000    46.105
                                                           1942
OUTPUT BELOW THIS POINT IS PER TURBOCHARGER::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

        RC   COMP EF      NCC           WCC            QC         AREA IN        DT IN         DT EX       EFSF  DT HT
    1.3642   0.7200    65000 RPM    0.1818 LB/S    142.68 CFM    1.6696 SQIN   1.7030 IN     2.6660 IN   1.0000   8.0
             0.6430                 0.0850 KG/S    0.0673 M3/S  1077.16 SQMM  43.256 MM     67.716 MM

      RETS   TURB EF      NCT           WCT          U/V' VANE THRT        VANE HT       ROT TH A        EFSF PW2/PW1
    1.3107   0.8382    45761 RPM    0.1993 LB/S    0.7615   0.1910 IN     0.2500 IN     1.6500 SQIN 1.0000 1.0003
(  1.3107)(  0.8382)(  0.0000)      0.0932 KG/S             4.8526 MM     6.3500 MM    1064.51 SQMM

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	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	593.60	593.60	1076.63	1054.53	1047.14	986.04
TEMP-DEG C	15.13	15.13	15.13	15.13	56.58	56.58	324.93	312.65	308.55	274.60
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	14.700	14.700	14.700	14.700	20.054	20.054	49.626	19.463	19.463	14.850
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.3823	1.3823	3.4206	1.3416	1.3416	1.0235
FLOW-LB/S	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1858	0.1858	0.1858	0.1858
WRT/D-LB/S	0.1818	0.1818	0.1818	0.1818	0.1425	0.1425	0.0793	0.2000	0.1993	0.2535
FLOW-KG/H	296.9110	296.9110	296.9110	296.9110	296.9110	296.9110	303.3510	303.3510	303.3510	303.3510
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation number 46, TABLE VI

*****.967824XEFITH*****

4 CYL DIESEL ENGINE CALCULATION ID=00/18/00 00:04:41 , 10.95

WITH 1 TURBOCHARGER

ENG SPEED	TORQUE	NET POWER	BMEP	FMEP	ENG DELP(I-E)	VOL EFF	I. THRMO EFF
2000 RPM	40.60FT-LB	15.46 HP	27.09 PSIA	28.48 PSIA	-0.11 PSIA	0.9108	0.4294
	55.05 N-M	11.53 KW	1.87 BAR	1.96 BAR	-0.01 BAR	(0.911,0.911)	(1.0000)

DISPLCMNT	STROKE	COMPR RAT	AMB TEMP	AMB PRES	EQ RAT	TF	FMEP ADJ	QDOT
226.00 INC3	4.5000 IN	16.0000	59.000DEG F	14.700 PSIA	0.2460	-0.3550	1.0000	0.0000
3.70LITER	114.30 MM		15.130DEG C	1.0132 BAR	-10.6604	0.286	9.0079	

COOL EFF	% BLOW BY	LEAK9-A	LEAK9-5	LEAK DT5	BSHC	BSCO	BSNO	BOSCH
0.0000	0.0000	0.0000	0.0000	0.0000	5.0995	8.1041	5.5847	0.6172

VAP PWR	VAP MEP	T MIX	T COMPRN	VAP DT	P COMPRN	VAP DP	WR/WG5
-0.00 HP	-0.00 PSI	605.06 DEG R	1763.74 DEG R	0.00 DEG R	928.45 PSI	0.00 PSI	0.0427
-0.00 KW	-0.00 BAR	62.95 DEG C	706.66 DEG C	0.00 DEG C	64.00 BAR	0.00 BAR	

F#	TYPE	M/MTOT	%VAP-MIX	VAP EF	BSFC-#/HH	BSFC-G/KH	LB/HR	CARB DP/P	AIR/FUEL
3	DIESEL	1.0000	0.0000	1.0000	0.6896	419.45	10.66	0.0000	61.043

1.458

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER::

RC	COMP EF	NCC	WCC	QC	AREA IN	DT IN	DT EX	EFSF	DT HT
1.3542	0.7200	63500 RPM	0.1000 LB/S	141.84 CFM	1.6696 SQIN	1.7030 IN	2.6660 IN	1.0000	6.3
	0.6560		0.0045 KG/S	0.0669 M3/S	1077.16 SQMM	43.256 MM	67.716 MM		

RETS	TURB EF	NCT	WCT	U/V'	VANE THRT	VANE HT	ROT TH A	EFSF	PW2/PW1
1.3494	0.8236	46998 RPM	0.1823 LB/S	0.7448	0.1609 IN	0.2500 IN	1.6500 SQIN	1.0000	1.0001
(1.3494)	(0.8236)	(0.0000)	0.0852 KG/S		4.0876 MM	6.3500 MM	1064.51 SQMM		

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	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	519.00	519.00	519.00	519.00	590.20	590.20	969.99	953.29	947.43	886.36
TEMP-DEG C	15.13	15.13	15.13	15.13	54.69	54.69	265.68	256.41	253.15	219.22
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	14.700	14.700	14.700	14.700	19.907	19.907	42.416	20.014	20.014	14.831
PRES-BAR	1.0132	1.0132	1.0132	1.0132	1.3721	1.3721	2.9236	1.3795	1.3795	1.0223
FLOW-LB/S	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1837	0.1837	0.1837	0.1837
WRT/D-LB/S	0.1000	0.1000	0.1000	0.1000	0.1423	0.1423	0.0870	0.1829	0.1823	0.2380
FLOW-KG/H	295.1630	295.1630	295.1630	295.1630	295.1630	295.1630	299.9990	299.9990	299.9990	299.9990
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566

Computer output for calculation 47, TABLE VI

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***** 967824XEFITH*****
 4  CYL DIESEL ENGINE CALCULATION               ID=00/18/00 00:25:45  , 56.6333
    WITH  1  TURBOCHARGER

 ENG SPEED         TORQUE      NET POWER         BMEP           FMEP        ENG DELP(I-E)    VOL EFF      I.THRMO EFF
     2000 RPM     -0.00FT-LB     -0.00 HP       -0.00 PSIA      27.54 PSIA     -1.30 PSIA     0.9062          0.3748
                  -0.00 N-M.     -0.00 KW       -0.00 BAR        1.90 BAR      -0.09 BAR  (0.910,0.906)   ( 1.0000)

 DISPLCMNT         STROKE      COMPR RAT        AMB TEMP       AMB PRES          EQ RAT       TF   FMEP ADJ      QDOT
   226.00 IN^3    4.5000 IN     16.0000          59.000DEG F    14.700 PSIA      0.1462   -0.3550   1.0000    0.0000
     3.70LITER    114.30 MM                      15.130DEG C    1.0132 BAR      -6.3295    0.1862   4.5431

  COOL EFF       % BLOW BY   LEAK9-A    LEAK9-5  LEAK DT5      BSHC        BSCO        BSNO       BOSCH
  0.0000          0.0000     0.0000     0.0000   0.0000%-360722.0000%-550073.0000%-229375.0000    0.9475

   VAP PWR          VAP MEP          T MIX        T COMPRN          VAP DT         P COMPRN          VAP DP          WR/WGS
     0.00 HP         0.00 PSI     600.51 DEG R   1752.17 DEG R     0.00 DEG R     929.35 PSI        0.00 PSI       0.0514
     0.00 KW         0.00 BAR      60.42 DEG C    700.23 DEG C     0.00 DEG C      64.06 BAR        0.00 BAR

 F#   TYPE    M/MTOT  %VAP-MIX   VAP EF BSFC-#/HH BSFC-G/KH     LB/HP CARB DP/P  AIR/FUEL

 3 DIESEL    1.0000   0.0000    1.0000%-29638.4000%-18028400.00     6.33    0.0000   102.699

OUTPUT BELOW THIS POINT IS PER TURBOCHARGER::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::.

        RC   COMP EF       NCC            WCC            QC          AREA IN          DT IN          DT EX         EFSF  DT HT
    1.3542   0.7200     63500 RPM     0.1805 LB/S    141.59 CFM     1.6696 SQIN     1.7030 IN      2.6660 IN     1.0000   4.4
             0.6742                   0.0843 KG/S    0.0668 M3/S    1077.16 SQMM    43.256 MM      67.716 MM

       RETS  TURB EF       NCT            WCT          U/V'  VANE THRT          VANE HT         ROT TH A        EFSF PW2/PW1
    1.4318   0.7911     50018 RPM     0.1603 LB/S     0.7276   0.1263 IN       0.2500 IN       1.6500 SQIN  1.0000 1.0001
 ( 1.4318)( 0.7911)( 0.0000)          0.0749 KG/S              3.2084 MM       6.3500 MM      1064.51 SQMM

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                    AMBIENT   CARB IN  CARB OUT  COMPR IN COMPR OUT INTAKE MAN CYL VL CLS  EXH MAN   TURB IN  TURB OUT
 TEMP-DEG R          519.00    519.00    519.00    519.00    588.18    588.18    851.98    840.62    836.51    773.77
 TEMP-DEG C           15.13     15.13     15.13     15.13     53.57     53.57    200.12    193.81    191.53    156.67

 VAP DT-R                                  0.00                0.00      0.00
 VAP DT-C                                0.0000              0.0000    0.0000
 VAP FRCTN OF FUEL #  3                  0.0000              0.0000    0.0000

 PRES-PSIA           14.700    14.700    14.700    14.700    19.907    19.907    34.[illegible]    [illegible]1.209    21.209    14.813
 PRES-BAR            1.0132    1.0132    1.0132    1.0132    1.3721    1.3721    2.[illegible]458    [illegible].4619    1.4619    1.0210

 FLOW-LB/S           0.1804    0.1804    0.1804    0.1804    0.1804    0.1804    0.1822    0.1822    0.1822    0.1822
 WRT/D-LB/S          0.1805    0.1805    0.1805    0.1805    0.1419    0.1419    0.1008    0.1607    0.1603    0.2208
 FLOW-KG/H         294.6560  294.6560  294.6560  294.6560  294.6560  294.6560  297.5250  297.5250  297.5250  297.5250

 LOSS COEF           0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.1566
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Computer output for calculation 48, TABLE VI

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*****.967824XEFITH*****
 4  CYL DIESEL ENGINE CALCULATION.            ID=00/20/00 21:28:42  , 63.15
    WITH  1  TURBOCHARGER

ENG SPEED        TORQUE      NET POWER        BMEP          FMEP        ENG DELP(I-E)    VOL EFF       I.THRMO EFF
    2000 RPM     128.92FT-LB    49.09 HP      86.02 PSIA    30.54 PSIA      2.23 PSIA     0.9564           0.4129
                 174.81 N-M     36.61 KW       5.93 BAR      2.11 BAR       0.15 BAR  (0.948,0.956)   (  1.0000)

DISPLCMNT        STROKE      COMPR RAT        AMB TEMP      AMB PRES         EQ RAT        TF  FMEP ADJ      QDOT
   226.00 IN3    4.5000 IN    16.0000          90.10DEG F    10.916 PSIA     0.6578   -0.3550    1.0000    0.0008
     3.70LITER   114.30 MM                     32.41DEG C    0.7524 BAR    -22.7654    0.3701   22.8976

 COOL EFF       % BLOW BY   LEAK9-A   LEAK9-5  LEAK DT5     BSHC      BSCO      BSNO      BOSCH
  0.0000         0.0000     0.0000    0.0000    0.0000    0.4046    0.7666   12.9132    1.6624

  VAP PWR        VAP MEP           T MIX         T COMPRN         VAP DT        P COMPRN         VAP DP          WR/WG5
    0.00 HP        0.00 PSI    696.63 DEG R   1986.98 DEG R     0.00 DEG R    791.84 PSI       0.00 PSI       0.0263
    0.00 KW        0.00 BAR    113.81 DEG C    830.68 DEG C     0.00 DEG C     54.58 BAR       0.00 BAR

F#   TYPE    W/WTOT  %VAP-MIX   VAP EF BSFC-#/HH BSFC-G/KH    LB/HR CARB DP/P  AIR/FUEL

 3 DIESEL   1.0000   0.0000    1.0000   0.4637    282.07     22.77   0.0000    22.826
                                                           3.115
OUTPUT BELOW THIS POINT IS PER TURBOCHARGER:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

       RC    COMP EF      NCC           WCC              QC           AREA IN          DT IN          DT EX       EFSF  DT HT
    1.5895   0.7200    76500 RPM    0.2001 LB/S    157.03 CFM     1.6696 SQIN     1.7030 IN      2.6660 IN    1.0000  17.1
             0.6223                 0.0935 KG/S    0.0741 M3/S   1077.16 SQMM     43.256 MM      67.716 MM

     RETS   TURB EF      NCT            WCT            U/V'  VANE THRT        VANE HT        ROT TH A         EFSF PW2/PW1
   1.3625   0.8396    47126 RPM    0.2448 LB/S    0.7340   0.2162 IN        0.2500 IN       1.6500 SQIN  1.0000 1.0000
(  1.3625)(  0.8396)(  0.0000)    . 0.1144 KG/S             5.4924 MM        6.3500 MM    1064.51 SQMM

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	AMBIENT	CARB IN	CARB OUT	COMPR IN	COMPR OUT	INTAKE MAN	CYL VL CLS	EXH MAN	TURB IN	TURB OUT
TEMP-DEG R	550.10	550.10	550.10	550.10	676.43	676.43	1526.47	1465.14	1449.57	1360.89
TEMP-DEG C	32.41	32.41	32.41	32.41	102.59	102.59	574.04	540.77	532.12	482.85
VAP DT-R			0.00		0.00	0.00				
VAP DT-C			0.0000		0.0000	0.0000				
VAP FRCTN OF FUEL # 3			0.0000		0.0000	0.0000				
PRES-PSIA	10.916	10.916	10.916	10.916	17.351	17.351	63.436	15.121	15.121	11.098
PRES-BAR	0.7524	0.7524	0.7524	0.7524	1.1960	1.1960	4.3725	1.0422	1.0422	0.7649
FLOW-LB/S	0.1443	0.1443	0.1443	0.1443	0.1443	0.1443	0.1507	0.1507	0.1507	0.1507
WRT/D-LB/S	0.2001	0.2001	0.2001	0.2001	0.1396	0.1396	0.0599	0.2461	0.2448	0.3232
FLOW-KG/H	235.6990	235.6990	235.6990	235.6990	235.6990	235.6990	246.0250	246.0250	246.0250	246.0250
LOSS COEF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1566